AF CENTER FOR ENVIRONMENTAL EXCELLENCE

Massachusetts Military Reservation

FEASIBILITY STUDY
AREA OF CONTAMINATION FS-1

FINAL

May 1999

Prepared for:
AFCEE/MMR
Installation Restoration Program
322 E. Inner Road, Box 41
Otis ANGB, MA 02542
DSA: 557-4670 COMM:508-968-4670

Submitted by
HAZARDOUS WASTE REMEDIAL ACTIONS Program
Oak Ridge, Tennessee 37831-7606
managed by
LOCKHEED MARTIN ENERGY SYSTEMS
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05OR21400

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ACRONYMS

ADD	average daily dose
AFCEE	Air Force Center for Environmental Excellence
ANG	U.S. Air National Guard
AOC	Area of Contamination
ARAR	applicable or relevant and appropriate
ARNG	Massachusetts Army National Guard
AWQC	Ambient Water Quality Criteria
BBM	Buzzards Bay moraine
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Contract Laboratory Program
COC	contaminant of concern
COPC	contaminant of potential concern
CSF	cancer slope factor
CT	central tendency
DPH	Department of Public Health (Massachusetts)
EAT	Eastern Aircraft Turnaround
EDB	ethylene dibromide
ER-L	Effects Range-Low
FS	Feasibility Study
GAC	granular activated carbon
GC	gas chromatograph
gpm	gallons per minute
HARM	Hazard Assessment Rating Methodology
HAZWRAP	Hazardous Waste Remedial Actions Program
HEC	health/risk equivalent concentration
HI	Hazard Index
HQ	Hazard Quotient
HSL	Hazardous Substances List
IEUBK	Integrated Exposure Uptake Biokinetic (Model)
IRP	Installation Restoration Program
LOAEL	lowest observed adverse effect level
MADEP	Massachusetts Department of Environment Protection
MCL	maximum contaminant level
MCLG	maximum contaminant level goal

MCP	Massachusetts Contingency Plan
μg/dL	micrograms per deciliter
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MMCL	Massachusetts maximum contaminant level
MMR	Massachusetts Military Reservation
MPP	Mashpee pitted plain
MSL	mean sea level
MW	monitoring well
NCP	National Contingency Plan
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no observed adverse effect level
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O&M	operations and maintenance
PAVE-PAWS	Precision Acquisition Vehicle Entry–Phase Array Warning System
PCB	polychlorinated biphenyl
PRA	Preliminary Risk Assessment
RAO	remedial action objective
RAS	Routine Analytical Services
RCRA	Resource Conservation and Recovery Act
RfD	reference dose
RI	Remedial Investigation
RME	reasonable maximum exposure
ROD	Record of Decision
SDWA	Safe Drinking Water Act
SI	Site Inspection
SM	Sandwich moraine
STCL	soil target cleanup level
SVOC	semivolatile organic compound
TCL	Target Compound List
TOC	total organic carbon
TPH	total petroleum hydrocarbons
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UV	ultraviolet

VA	Veterans Administration
VOC	volatile organic compound
WAT	Western Aircraft Turnaround

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EXECUTIVE SUMMARY

This Feasibility Study (FS) describes the evaluation of potential alternatives for remediation of groundwater and surface water contamination associated with Area of Contamination (AOC) Fuel Spill No. 1 (FS-1) at the Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts. The FS presents a range of remedial alternatives to mitigate contamination determined to pose unacceptable risks to human health and/or the environment.

Risk assessment of samples collected in the source area indicates that surface soil and subsurface soil in the source area do not pose an unacceptable risk to human health or the environment. Groundwater samples in the source area did not contain levels of contamination meriting active remedial actions. Groundwater in the source area does merit monitoring to ensure that contaminants in the source area do not migrate. Groundwater samples from downgradient of the source area and surface water samples from the Quashnet River discharge zone of that groundwater contained elevated levels of ethylene dibromide (EDB). Risk assessments using data from downgradient groundwater samples and surface water samples indicate the need for potential active remedial actions on downgradient groundwater and surface water in the discharge area.

The FS process establishes remedial action objectives (RAOs) based on the contaminants of concern (COCs), contaminated media, exposure routes, and potential for risk of harm to human and/or ecological receptors evaluated in the remedial investigation (RI). Remedial response actions are developed to meet the RAOs. Actions that fulfill the technical feasibility criteria are evaluated for their relative effectiveness, ability to be implemented at the site, and cost-effectiveness. The evaluation process then identifies the most appropriate remedial response actions, which are either singularly developed into remedial alternatives or combined with other actions to form a more comprehensive remedial alternative. Alternatives that emerge from this process are subjected to more detailed analysis and comparison.

The data used in developing this FS for AOC FS-1 were obtained from the RI report, *Remedial Investigation Report, Area of Concern FS-1*, Final (HAZWRAP 1999). The referenced report was prepared by the Hazardous Waste Remedial Actions Program (HAZWRAP) for the Air Force Center for Environmental Excellence (AFCEE) at MMR.

Determination of COCs for the FS-1 FS were based on risk assessments, evaluations of the risk assessments with respect to site conditions, and comparison to other standards. The chemicals in groundwater at AOC FS-1 that resulted in unacceptable risk to potential human populations for maximum concentrations were EDB, chloroform, iron, and arsenic. Toluene, lead, and thallium exceeded federal drinking water standards [termed maximum contaminant levels (MCLs)] in the source area. The listed chemicals are contaminants of potential concern (COPCs). Review of site conditions shows that groundwater COPCs are divided into two areas: the source area and the downgradient impacted area. The COCs for the source area are toluene, lead, and thallium. These compounds are relatively immobile and have not moved away from the on-base source area. The COC for the downgradient impacted area is EDB. Iron and chloroform were not retained as COCs because the mean concentrations, which are representative of the overall contamination levels, do not result in unacceptable risk levels. Arsenic was not retained as a COC because of the limited number of detections. EDB also contributed to risk greater than

acceptable Massachusetts levels for people who may eat fish from the upper reaches of the Quashnet River. No COCs were identified for source area soils.

The RAOs for AOC FS-1 are:

- Prevent or reduce exposure to groundwater contaminant(s) of concern exceeding cleanup standards in groundwater.
- Restore the aquifer to beneficial uses within a reasonable time frame.
- Prevent or reduce worker, recreational youth, and adult wader contact with Quashnet River water containing unacceptable concentrations of EDB and ingestion of fish exposed to Quashnet River water containing unacceptable concentrations of EDB.

If active remedial alternatives are chosen, the following steps will be taken.

- Remediate the downgradient aquifer to federal and state drinking water standards (MCLs).
- When MCLs are achieved and before the system is shut off, perform a risk assessment to determine if unacceptable ecological or human health risks remain. If unacceptable risks are present, continue system operation and/or pursue additional measures as required to achieve acceptable risks.
- After acceptable risks have been achieved, evaluate the technical and economic feasibility of additional remediation to approach or achieve background concentrations.

This three-step process has been agreed to solely at MMR because of the unique circumstances presented by the location of the FS-1 plume within the sole-source aquifer of Upper Cape Cod.

MMR Remedial Technology Evaluation And Applicable Or Relevant And Appropriate Requirements Handbook (HAZWRAP 1989), the U.S. Environmental Protection Agency (USEPA)/AFCEE *Remediation Technologies Screening Matrix and Reference Guide* (USEPA 1994), and other sources were used to identify and screen technologies/process options that could achieve the established RAOs. The screening of technologies/process options considered the effectiveness, implementability, and cost associated with achieving the RAOs in accordance with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (USEPA 1988a).

As part of an expedited cleanup initiative, AFCEE has developed a pilot test involving groundwater extraction and treatment at the Quashnet River bogs where the leading edge of the EDB plume is discharging. The pilot test is described in *Quashnet River Bogs Pilot Test* (Jacobs 1999). Leading edged extraction involves shallow interceptor wells and one deep groundwater extraction well, treatment by granulated activated carbon, and discharge by reinjection and surface water discharge. Aspects of the pilot test are evaluated as potential technologies and process options. This FS incorporates the pilot test as portions of Alternatives 2B and 3B.

Five remedial alternatives were developed from technologies and process options that were determined to have the capacity of being technically and administratively implemented at the AOC, to satisfy in part, or as a whole, the short- and long-term requirements of the RAOs, and to be cost-effective. The five alternatives contain an individual or a combination of technology(ies)

and/or process option(s) tailored to achieve the RAOs for contaminated groundwater and surface water associated with AOC FS-1. The identified alternatives are:

Alternative 1	No Action
Alternative 2:	Limited Action
Alternative 2B:	Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge
Alternative 3:	Axial Well Extraction, Treatment, and Reinjection/Discharge
Alternative 3B:	Axial and Leading Edge Extraction, Treatment, and Reinjection/Discharge

A comprehensive comparison of the alternatives is contained in Section 9.2.

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1. INTRODUCTION

This Feasibility Study (FS) describes the evaluation of potential alternatives for remediation of groundwater contamination at Area of Contamination (AOC) FS-1 at Massachusetts Military Reservation (MMR) on Cape Cod, Massachusetts. The FS presents a range of remedial alternatives to mitigate site contamination determined to pose unacceptable risks to human health and/or the environment. This analysis of feasibility is based on the results of the Remedial Investigation (RI) conducted for AOC FS-1. The RI presents the types and distribution of contamination and the assessments of risks to potential human and ecological receptors. The RI concluded that risks at the source area based on a utility worker scenario were not greater than any target levels. Risk requiring action was quantified for groundwater and surface water.

The FS process establishes remedial action objectives (RAOs) based on the contaminants of concern (COCs), the contaminated media, the exposure routes, and the potential for risks to human and/or ecological receptors established in the RI. Response actions are then developed that will meet the RAOs. Actions that fulfill the technical feasibility criteria are evaluated for their relative effectiveness, their ability to be implemented at the site, and their cost-effectiveness. The evaluation process then identifies the most appropriate response actions, which are either singularly developed into remedial alternatives or combined with other actions to form a more comprehensive remedial alternative. Alternatives that emerge from this process are then subjected to more detailed analysis and comparison.

1.1 PURPOSE AND SCOPE

The purpose of this report is to develop, screen, and evaluate remedial alternatives that reduce potential risks posed by groundwater contamination and surface water contamination of AOC FS-1.

The data used in developing this FS for AOC FS-1 were obtained from the RI report, *Remedial Investigation Report, Area of Concern FS-*1, Final (HAZWRAP 1999). The referenced report was prepared by Commodore Advanced Sciences, Inc., and the Hazardous Waste Remedial Actions Program (HAZWRAP) for the Air Force Center for Environmental Excellence (AFCEE) at MMR.

1.2 DOCUMENT ORGANIZATION

This FS is organized into ten sections with supporting appendices. Section 1 provides a brief overview of the purpose, scope, and organization of the report. Section 2 presents site descriptions of AOC FS-1 and summarizes the RI activities and the analytical results for soil, subsurface soil, and groundwater samples. Section 3 presents the Preliminary Risk Assessment (PRA) results as reported in the RI. Section 4 presents the applicable or relevant and appropriate requirements (ARARs). In Section 5, the basis for site remediation is developed. This section includes a discussion of site-specific RAOs and volumes requiring remediation. Section 6 describes the remedial technologies and process options that could be used to meet the RAOs

and presents the results of a screening-level evaluation. In Section 7, the remediation technologies and process options retained as a result of the screening level evaluation are developed into remedial alternatives that are then subjected to additional screening of the developed remedial alternatives. Section 8 describes the detailed analysis of individual remedial alternatives retained from the development and screening process. Remedial alternatives are compared to each other based on the detailed analysis in Section 9. References are presented in Section 10.

2. ENVIRONMENTAL CONTAMINANT ASSESSMENT

2.1 MASSACHUSETTS MILITARY RESERVATION

Information presented in this section is based on the Final RI Report for AOC FS-1 prepared by HAZWRAP in 1999.

2.1.1 Location

MMR lies in the western portion of Cape Cod, Massachusetts. It occupies approximately 22,000 acres (35 square miles) within the towns of Bourne, Sandwich, Mashpee, and Falmouth in Barnstable County, as shown in Figure 2-1. (The figures are grouped at the end of the text following Section 10.) MMR is organized into four principal functional areas:

- Range Maneuver and Impact Area This 14,000-acre area occupies the northern 70% of MMR and is used for training and maneuvers.

- Cantonment Area Occupying 5,000 acres in the southern portion of MMR, this area is the location of administrative, operational, maintenance, housing, and support facilities for the base. This is the most actively used section of MMR. The Otis Air Force Base facilities, including the flight line area, are located in the southeast portion of the Cantonment Area.

- Massachusetts National Cemetery This area consists of 750 acres along the western edge of MMR and contains the Veterans Administration (VA) cemetery and support facilities.

- Cape Cod Air Force Station This area occupies 87 acres of the northern portion of the Range Maneuver and Impact Area and is known as the Precision Acquisition Vehicle Entry–Phase Array Warning System (PAVE-PAWS).

Figure 2-2 shows the location of AOC FS-1.

2.1.2 History of Operations

Military use of portions of MMR began as early as 1911; however, the majority of activity has occurred since 1935. Uses of MMR include operations by the U.S. Army, U.S. Navy, U.S. Coast Guard (USCG), U.S. Air Force (USAF), Massachusetts Army National Guard (ARNG), U.S. Air National Guard (ANG), and VA. The most intensive U.S. Army activity occurred during World War II from 1940 to 1944 and during demobilization after the war. From 1955 to 1970, the USAF maintained intensive aircraft operations along the flight line areas in the southeastern portion of the Cantonment Area. Airborne surveillance activities were phased out in the early 1970s.

Ongoing operations at MMR include ARNG, ANG, U.S. Army Reserve training, Air Station Cape Cod (operated by the USCG), the PAVE-PAWS missile and space vehicle-tracking system (operated by the USAF), and the Massachusetts National Cemetery.

2.1.3 Geography

MMR is located on two distinct types of terrain. The Cantonment Area lies on a gently southward-sloping outwash plain with elevations ranging from 100 to 140 feet above mean sea level (MSL). The area to the north and west of the Cantonment Area is dotted with irregular hills and lies in the southern extent of Wisconsin Age terminal moraines. Elevations in this area range from 100 to 250 feet above MSL, on the average. Kettle holes and depressions, some of which contain water, are found over the entire site.

Approximately 80% of MMR's 22,000 acres is undeveloped land that provides a natural habitat for wildlife. The remaining 20% of MMR has been developed to support various military needs. Forested areas on MMR occur mainly in the Range Maneuver and Impact Area, as shown in Figure 2-1, and are classified as pine-oak climax forests. The Cantonment and flight line areas consist of open, mowed grasslands.

2.1.4 Geology and Hydrogeology

The geology of western Cape Cod is composed of glacial sediments deposited during the retreat of the Wisconsin stage of glaciation between 7,000 and 85,000 years ago. The regional geology is dominated by three extensive sedimentary units: Buzzards Bay moraine (BBM), Sandwich moraine (SM), and Mashpee pitted plain (MPP). BBM and SM lie along the western and northern edges of western Cape Cod, respectively. MPP, which consists of poorly sorted, fine- to coarse-grained sands forming a broad outwash plain, lies between the two moraines. Underlying MPP are fine-grained, glaciolacustrine sediments and basal till at the base of the unconsolidated sediments. The BBM and SM are composed of ablation glacial till, which is unsorted material ranging from clay to boulder size that was deposited at the leading edge of two lobes of the Wisconsinian glacier at its farthest advance. These moraines form hummocky ridges.

The total thickness of unconsolidated sediments overlying bedrock varies from approximately 175 feet near the Cape Cod Canal in the northwest to approximately 325 feet at the thickest portion of the BBM; it decreases to about 250 feet near Nantucket Sound to the south. The portion of the overburden composed of MPP outwash sediments varies in thickness from approximately 225 feet near the moraines in the north to about 80 feet near the shore of Nantucket Sound. Glaciolacustrine sediments and till underlying MPP generally increase in thickness as the proportion of MPP sediments decreases. Bedrock, which has been mapped as a granodiorite, lies approximately 300 feet below ground surface (bgs).

A description of the overall hydrogeologic setting can be found in the Task 1-8 Hydrogeologic Summary Report (Jordan 1989). A single groundwater flow system underlies western Cape Cod, including MMR. The aquifer system is unconfined (in equilibrium with atmospheric pressure) and is recharged by infiltration from precipitation. Surface water runoff at MMR is virtually nonexistent (except on extreme slopes) because of the highly permeable nature of the sands and gravel underlying the area. The high point of the water table occurs as a groundwater mound beneath the northern portion of MMR. Groundwater flow generally radiates outward from this mound. The aquifer is bounded by the ocean on three sides; groundwater

discharges into Nantucket Sound on the south, Buzzards Bay on the west, and Cape Cod Bay on the north. The Bass River in Yarmouth forms the eastern lateral aquifer boundary.

Surface water is present at MMR as intermittent streams in a few of the drainage swales and as ponds in kettle holes on MPP. The kettle hole ponds are depressions of land surface below the water table. On a regional scale, these kettle hole ponds influence groundwater flow in a manner similar to that of large aquifer heterogeneities: the larger or deeper the pond, the greater the effect on slope and direction of the regional water table near the pond. While horizontal groundwater flow is dominant in the aquifer system, vertical flow driven by piezometric head differences is important in areas near some of the ponds.

MPP consists of coarse-grained sand and gravel outwash sediments underlain by finer-grained sediments. The hydraulic conductivity of the outwash sediments has been measured at up to 380 feet/day. Hydraulic conductivity of the fine-grained sediments was observed to be only 2 to 10% of the outwash. Therefore, the bulk of regional groundwater flow is transmitted through the upper outwash unit; horizontal flow velocities range from 1 to 3.4 feet/day. The hydraulic gradient across MMR ranges from about 0.0014 to 0.0018 feet/feet.

2.1.5 Groundwater Use

The primary drinking water supply for MMR comes from a groundwater supply well located on the base installed in glacial outwash. The adjacent towns of Bourne, Falmouth, Mashpee, and Sandwich also derive their drinking water from supply wells. Falmouth has a reservoir for storage of drinking water obtained from groundwater. The water supply wells at MMR and the surrounding towns range from 40 to 412 feet deep; the majority of wells extend to depths of 50 to 100 feet bgs. In areas where public water supply lines are not available, residents use private wells for domestic water supplies.

2.2 AOC FS-1

2.2.1 Site Description

The following section describes the physical characteristics of the study area including demographics, land use, geological setting, hydrogeologic setting, and other notable features such as the cranberry bogs and Quashnet River. This industrialized region includes structures, runways, and taxiways for the support of flight operations. The FS-1 source area is located within the flight line area and includes the Eastern Aircraft Turnaround (EAT) and the Western Aircraft Turnaround (WAT). The EAT and WAT are constructed of concrete and asphalt and are located in an area once used as a source for borrow material. The area containing the EAT and the WAT is sparsely vegetated, and the northern and southern boundaries of the borrow area are denoted by steep soil slopes capped by heavily vegetated forest. Though the source area includes both the EAT and WAT, the source area concerns lie mainly in the WAT area.

2.2.2 Land Use

Although land use in areas adjacent to MMR is mainly residential, recreational, and agricultural, few residences exist in the area between the FS-1 source area and the discharge point for groundwater (cranberry bog and the Quashnet River). The off-base land adjacent to this portion of MMR is heavily wooded and undeveloped with the exception of one home at the end of Ashumet Road, cranberry bogs, and an abandoned borrow pit. Ashumet and Johns Ponds are located in the general vicinity but are not expected to be affected by contamination from AOC FS-1. Agricultural land adjacent to this portion of MMR includes active cranberry bogs located east of Johns Pond and south of the MMR base boundary. The Township of Mashpee has investigated one area south of the FS-1 source area for the potential site of a drinking water well (P-11) (D.L. Maher 1992).

2.3 GEOLOGICAL SETTING

The AOC FS-1 source area as well as the downgradient areas are underlain by the MPP. The MPP is composed of poorly sorted fine- to coarse-grained glacial outwash sands. Fine-grained glaciolacustrine sediment and basal till have been described below the unconsolidated sediments of the MPP (ABB-ES 1994). Borings were advanced to the glaciolacustrine deposits in the 1997–1998 RI. Site soils and soils downgradient of AOC FS-1 are characterized by 180 to 200 feet of primarily sandy soils with some gravel.

Discontinuous lenses of finer-grained silts were encountered within the sandy strata during the RI. However, stratigraphic analysis of the logs did not allow interpretation of large-scale low permeability structures. Glaciolacustrine deposits were encountered in the bottom of the borings. The deposits were sandy silt through a plastic silty clay. Fines increased with depth.

Additional stratigraphy specific to the bog area was developed during recent investigations conducted by Jacobs Engineering Group. Drive points installed within the bogs encountered varying thicknesses of peat in the bogs. Peat was inferred at depths ranging from 4 to 41 feet bgs. Soils underlying the peat are similar to soils upgradient of the bog.

2.4 HYDROGEOLOGIC SETTING

The aquifer underlying AOC FS-1 is unconfined and designated as a sole-source aquifer by the U.S. Environmental Protection Agency (USEPA). Aquifer recharge occurs from precipitation. The aquifer is composed of unconsolidated sediments consisting of the MPP and finer-grained till and lacustrine sediments. The industrialized area of MMR (including the flight line and AOC FS-1) is located on the southern and southeastern flanks of the groundwater mound. Groundwater beneath AOC FS-1 flows from the north to the south and southeast. In general, groundwater flow paths at MMR appear to dip slightly into the aquifer.

Data gathered during all investigations have been used to construct maps representing the surface of the water table. Work performed during the Task 1-8 study (Jordan 1989) indicates that groundwater flow direction may oscillate (up to 9°) around a mean. Groundwater flow

directions as indicated by (1) water table contour maps developed from data collected during the Task 1-8 study (Jordan 1989), (2) the initial RI (ABB-ES 1991), (3) Mashpee Groundwater Study, Task 5 (Jordan 1990b), (4) water level measurements collected by HAZWRAP in March of 1993, (5) the Southeast Region Groundwater Operable Unit (SERGOU) RI (ABB-ES 1994), (6) the groundwater contour map produced for Waquoit Bay (Cape Cod Commission 1992), and (7) the most recent two synoptic measurements made by HAZWRAP in January and April 1998 show convergence of groundwater contours on the cranberry bog east of Johns Pond.

During the 1997–1998 Supplemental RI, two synoptic water level measurement events were conducted in January and April 1998. These snapshots incorporated most wells in the assumed flow path of AOC FS-1 and sufficient auxiliary wells to develop local groundwater contours from the source area to the Quashnet River. In addition, these events incorporated surface water level measurements from Mashpee and Johns Ponds and from three staff gauges/weirs located along the Quashnet River in the cranberry bogs east of Johns Pond. Data from these measurements are illustrated in the water table contour maps of Figures 2-3 and 2-4. For most of the area upgradient of the Quashnet cranberry bogs, flow gradients are essentially horizontal across the entire saturated zone. This horizontal flow is consistent until within a few hundred feet of the cranberry bogs, where upward vertical gradients start to increase dramatically and induce groundwater upwelling into the bogs.

2.5 SURFACE WATER AND CRANBERRY BOGS

The cranberry bog east of Johns Pond (Figure 2-2) is an important feature for this site. The Quashnet River is fed by a controlled head gate located on the northeast corner of Johns Pond. From there, the river flows through the large cranberry bog adjacent to Johns Pond and onward to Waquoit Bay. The upper reaches of the Quashnet River are fed by groundwater discharge.

The water budget presented by HAZWRAP indicated that the majority of flow in the Quashnet in the area immediately downgradient of Johns Pond was derived from groundwater discharging to the cranberry bogs. The calculations indicating groundwater discharge to the Quashnet River contained in the HAZWRAP water budget and published USGS reports (Barlow and Hegg 1993) were confirmed by Jacobs measurements (Jacobs 1997) in August 1997. Surface water flow measurements were taken at weirs from two upstream locations, one midstream location, and at a single downstream outlet location. Stepwise increases in the volume of surface water along the Quashnet River at the midstream and outlet locations clearly demonstrate additions on the order of 2,000 to 2,500 gpm of water to the bogs from groundwater upwelling.

2.6 SITE HISTORY

AOC FS-1was used by the 551st Airborne Early Warning and Control Wing to test fuel dump valves between 1955 and 1970. Records searches indicate that EC-121 Super Constellation aircraft were parked at the EAT and WAT and fuel valves were tested. Both the EAT and WAT were investigated during the course of the SI and the RI. The valves were

opened and the fuel allowed to drain. Initially, records suggest the fuel was hosed off the concrete. Records also indicate that the fuel was collected in 55-gallon barrels. The exact quantity of fuels released onto the concrete is unknown.

2.6.1 Previous Investigation History

The following investigations were conducted at AOC FS-1. Relevant figures from the investigations are contained in Appendix A.

2.6.1.1 Phase I Records Search

An Installation Restoration Program (IRP) Phase I records search conducted by Metcalf & Eddy identified AOC FS-1 as an area of potential environmental contamination based on prior waste management practices (Metcalf & Eddy 1983). Using the Hazard Assessment Rating Methodology (HARM) rating system, AOC FS-1 received a score of 71. Because of the high potential for contaminant migration of fuel components within soils, Metcalf & Eddy recommended that further exploratory work be conducted at the study area.

2.6.1.2 Phase II, Stage I Study

A Phase II, Stage 1 confirmation/quantification study was performed by R. F. Weston, Inc. (Weston 1985). This field exploration program at the AOC FS-1 source area consisted of eight test pits and one water table monitoring well. Four of the test pits were excavated adjacent to the WAT; the remaining four test pits were located in a swale approximately 1,600 feet southwest of the WAT. Monitoring well RFW-11 was installed approximately 200 feet south of the WAT. Fuel-related contamination was not detected in soil and groundwater samples submitted for laboratory analyses.

An expanded Phase I records search confirmed earlier findings (Jordan 1986). The study area received a HARM rating of 78.9 and was classified as a Priority I area. Phase II studies (confirmation/quantification) were recommended for AOC FS-1 based on the potential for on-site contamination and off-site contaminant migration.

2.6.1.3 Site Inspection

A Site Inspection (SI) of MMR Priority I areas that included the AOC FS-1 source area was conducted (Jordan 1989 and 1990a). The SI program at AOC FS-1 concentrated on the source area and included a soil gas survey, the installation of one soil boring (TB-3), and three monitoring wells (MW-1, MW-2, and MW-4). Thirty soil gas sampling points were located where fuel valve testing was suspected to have been conducted. Samples were analyzed for chlorinated hydrocarbons and fuel-related hydrocarbons (i.e., benzene, toluene, and xylene).

Soil and groundwater samples collected during the SI program were submitted for laboratory analysis. Additional explorations were recommended to delineate the extent of residual contamination in the vicinity of the WAT and downgradient area.

2.6.1.4 Mashpee Groundwater Study, Task 5

The Mashpee Groundwater Study, Task 5 (Jordan 1990b) was performed to determine the impact of MMR waste disposal activities on groundwater in the Mashpee Township adjacent to MMR. This program consisted of two stages. Stage I involved installation of 14 water table monitoring wells, completion of 3 deep borings to characterize the geologic conditions, establishment of survey markers, and collection of water level data from 35 existing observation wells. Water table wells were used to determine horizontal groundwater flow direction.

The second phase of the Mashpee Groundwater Study focused on installing and sampling multilevel well clusters for characterizing groundwater quality. Two of these well clusters, MW-516 and MW-517, were installed potentially downgradient of AOC FS-1. The MW-516 cluster contains five wells (screened depths below grade are shown in brackets [ ]): MW-516A [120–125 feet], MW-516B [100–105 feet], MW-516C [80–85 feet], and MW-516D [60–65 feet]. These wells were located next to the Phase I water table well WT-11, which was predesignated as MW-516E [34–44 feet]. The MW-517 cluster includes monitoring wells MW-517A [120–125 feet], MW-517B [100–105 feet], MW-517C [80–85 feet], MW-517D [60–65 feet], and MW-517E [43–46 feet].

During drilling activities for MW-516A, 20 soil samples were collected and screened in the field using a field gas chromatograph (GC). Two samples were submitted for analysis using Routine Analytical Services (RAS) Contract Laboratory Program (CLP) methods for Hazardous Substances List (HSL) volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and inorganic metals. These samples were collected at 33–35 bgs and 103–105 feet bgs. Soil samples were collected during drilling for MW-517A at the 45- to 47-ft-bgs and 125- to 127-ft-bgs intervals and submitted for similar analyses.

Six rounds of groundwater samples were collected from each of the wells in the two well clusters. Round 1 sampling was conducted in May of 1987. These samples were submitted to a fixed-base laboratory for analysis of HSL VOCs, SVOCs, and elemental analysis by RAS CLP methods. Rounds 2, 3, and 4 were conducted in June, July, and August 1987, respectively, and samples were submitted for RAS CLP analysis for VOCs only. Rounds 5 and 6 were conducted in December 1987 and February 1988, respectively. These samples were not analyzed by CLP methods. Analysis was specifically targeted towards trichloroethane, perchloroethylene, toluene, and methyl ethyl ketone by a modified USEPA Method 8020.

2.6.1.5 Remedial Investigation

An RI was initiated at AOC FS-1 in 1990. The RI for AOC FS-1 was partitioned into two operable units: (1) FS-1A source area and (2) FS-1B downgradient groundwater. At the source area (FS-1A), seven monitoring wells (MW-6, MW-7, MW-8, MW-412, MW-413, MW-414, and MW-415) and two test borings (TB-5 and TB-411) were installed. Twelve subsurface soil samples from six of the borings were collected. Groundwater samples from all new and previously installed source area wells also were collected.

During the FS-1B investigation, downgradient monitoring wells were installed using screened augers. A total of 53 groundwater screening samples were collected at various depths

below grade and analyzed using a field GC. Analytical results were used to determine vertical screen placement in the permanent monitoring wells. The downgradient investigation involved the installation of two monitoring well fences and one touchpoint well. Monitoring well fence 1 includes MW-4A, MW-9, MW-10A, MW-10B, MW-41, and MW-42. Existing well MW-4 was incorporated into fence 1. These wells are located approximately 500 feet downgradient of the WAT. Installation of monitoring well fence 2 includes MW-11, MW-12, MW-13, MW-112, and MW-121. Wells in this fence are located along the eastern MMR boundary (Figure 2-1). One touchpoint monitoring well, MW-14, was installed between the two well fences. Four water table monitoring wells were installed between AOC FS-1 and Route 130 in Mashpee. These wells are designated WT-15, WT-16, WT-17, and WT-18. Groundwater samples were collected and analyzed from all downgradient monitoring wells except water table wells designated "WT." Hydraulic conductivity testing was performed in the following wells: MW-4, MW-4A, MW-10A, MW-10B, MW-11, MW-12, and MW-112.

2.6.1.6 Source Area Ethylene Dibromide Study

The multisite ethylene dibromide (EDB) study *Technical Memorandum, Ethylene Dibromide Study* (ABB-ES 1993) included collection of groundwater samples from AOC FS-1 source area wells. Groundwater samples from MW-2, MW-6, MW-7, MW-8, MW-11, RFW-11, and MW-42 were analyzed for EDB using USEPA Method 504.

2.6.1.7 Geoprobe® Investigation

Multidepth Geoprobe® groundwater screening was conducted for the area downgradient of the AOC FS-1 source area to evaluate the presence or absence of fuel-related contamination (ASI 1995). Six Geoprobe® fences were installed beginning at the AOC FS-1 source area and progressing downgradient to the cranberry bog adjacent to Johns Pond. Two additional Geoprobe® borings were installed in the cranberry bog. Groundwater was collected at multiple depths in each boring beginning at the maximum depth achieved to the water table. These samples were analyzed in a field laboratory for benzene, toluene, ethylbenzene, and xylenes and total petroleum hydrocarbons (TPH). Based on the results from this investigation, screened auger borings were installed at three of the Geoprobe® sites. During drilling, samples were submitted to a local laboratory for analysis of fuel-related compounds. Samples were also collected from monitoring wells MW-516B [80–85 feet bgs], MW-516C [100–105 feet bgs], MW-517B [80–85 feet bgs], and MW-517C [100–105 feet bgs]. These samples were submitted to a local laboratory. Groundwater samples collected from monitoring wells MW-15, MW-16, and MW-17 were submitted for analysis in accordance with the USEPA CLP methods.

2.6.1.8 Supplemental Surface Soil Sampling

Supplemental source area surface soil sampling was conducted in September of 1995 to provide additional surface soil data for the risk assessment. Five surface soil samples were collected from the area surrounding the WAT and were submitted to a fixed-based laboratory for analysis of VOCs, SVOCs, pesticides, and polychlorinated biphenyls (PCBs), and Target Analyte List inorganics in accordance with USEPA CLP protocols.

2.6.1.9 SERGOU Remedial Investigation

Work not performed specifically for AOC FS-1 but applicable to discussions of the site was conducted during the SERGOU RI. Monitoring wells MW-538A, MW-538B, MW-538C, MW-552A, MW-552B, MW-552C, MW-552D, MW-553A, MW-553D, MW-556A, MW-556B, MW-556C, and MW-557 were installed during the SERGOU RI and are located downgradient of the AOC FS-1 site.

Samples collected from all of these wells were analyzed for VOCs, SVOCs, and inorganics in accordance with USEPA CLP protocols.

2.6.1.10 1997–1998 Supplemental Investigations

Additional downgradient and upgradient investigations were initiated as the result of public comments concerning the AOC FS-1 RI and related reports. Groundwater investigations were conducted in two separate phases that moved in "fences" from downgradient areas near the Quashnet bogs upgradient toward the presumed FS-1 source. The primary emphasis was on tracking the EDB plume identified in wells at the cranberry bog during the initial phase. The first phase occurred from August to October 1997 (13 locations, 16 wells, 2 piezometers), and the second phase occurred in March and April 1998 (13 locations, 16 wells). A total of 26 screened auger borings were advanced to refusal or to a maximum depth of 250 feet. Screened auger groundwater samples were collected every 10 feet as the augers were advanced. Screened auger samples were submitted for rapid chemical analyses of selected VOCs, EDB, and metals. Thirty-two permanent wells were installed based on the results of the screening analyses.

Additional groundwater samples were collected in the downgradient area in the vicinity of the bogs by Jacobs Engineering during late summer and fall. Drive points were advanced at 23 locations, and 18 samples were collected for EDB analysis. Subsequent to drive point installations, four wells and one piezometer were installed in the vicinity of the bog. Installation of the wells included screened auger sampling for EDB and VOCs. Permanently installed wells were sampled for target analytes. Applicable figures and tables from the report *Quashnet River Bogs Pilot Test* (Jacobs 1999) are contained in Appendix E.

2.6.1.11 Surface Water

Surface water sampling and laboratory analysis has occurred in three separate events at a number of locations in the eastern half of the Quashnet cranberry bogs. A total of 26 different locations were sampled by Jacobs Engineering. Twenty-two locations were sampled in August 1997, 10 locations were sampled in February 1998 (the bog was flooded during this event), and 7 locations were sampled in May 1998. Laboratory analysis has included EDB for each event and VOCs and SVOCs for the May 1998 event.

2.6.1.12 Sediment

Sediment sampling and laboratory analysis were conducted by Jacobs Engineering in May 1998 at seven locations where surface water was also collected. Laboratory analysis of sediment samples included EDB, VOCs, SVOCs, and metals.

2.6.1.13 1999 Source Area Sampling

Groundwater samples were collected from selected wells in the source area. The samples were collected to reevaluate lead, toluene, and methylene chloride in the source area. Wells were sampled for EDB, VOCs, SVOCs, and metals. Results of the sampling are contained in Appendix D.

2.7 CONTAMINATION ASSESSMENT

Details of the nature and extent of contamination associated with AOC FS-1 are presented in the RI report for AOC FS-1 (HAZWRAP 1999). The following sections summarize the field investigation findings.

2.7.1 Surface Soils

Surface soil samples did not contain significant quantities of organic compounds. No VOCs were quantifed. All SVOC and pesticides/PCBs concentrations were below soil target cleanup level (STCL) clean fill criteria. Aluminum, barium, chromium, and manganese were detected at concentrations slightly above established arithmetic mean background concentrations. Only chromium was above STCL clean fill criteria. The quantified concentration and the STCL are, respectively, 7.4 mg/kg and 6.8 mg/kg. Concentrations of lead were detected from 1.3 to 114 mg/kg.

2.7.2 Subsurface Soils

Minimal concentrations of regulated compounds were quantified during field investigations. Compound-specific VOCs were not quantified with one exception: elevated levels of methylene chloride were detected. However, it was assumed that the detection was not site related because there was no site history of its use at AOC FS-1. Methylene chloride is not a COC. It was determined that the detected concentrations were most likely laboratory artifacts. In addition to the fact that there is no site history of methylene chloride, there were multiple anomalous detections of methylene chloride from samples at other locations from the same laboratory during the same period. The only SVOC detected was bis(2-ethylhexyl)phthalate in a single soil boring sample. Lead was the only metal detected above background in subsurface soils. No VOCs or pesticides/PCBs were detected.

The concentrations of elements and compounds in source area soils were evaluated for the potential to contribute additional contamination to groundwater. All detected compounds and elements were compared to specific concentrations considered protective of groundwater in the MMR-specific STCLs. All compounds and elements, with the exception of methylene chloride, were at concentrations that would not contribute to additional groundwater contamination. Review of the methylene chloride detections and resampling in 1999 indicate the methylene chloride is not site related and may be a laboratory artifact.

The methylene chloride was considered a laboratory artifact because at the location with the highest detection of methylene chloride in soils below the water table [MW-7 at 140,000

micrograms per kilogram (μg/kg)], the groundwater did not contain methylene chloride. Methylene chloride is a highly soluble compound and if it existed in soils, it would also be in water at the same location. Methylene chloride is a common laboratory solvent recognized by USEPA as a potential false positive. Because of these two facts, it was determined that the detection in soils was a laboratory artifact and the methylene chloride was not present in soils. The 1999 sampling included sampling of groundwater for methylene chloride. Again, there were no detections of methylene chloride, confirming the hypothesis that methylene chloride was a sample artifact and is not present in soils at FS-1.

2.7.3 Groundwater

Two VOCs, toluene and methylene chloride, were quantified at levels above MCLs in source area wells. Maximum toluene concentrationswere 2,500 micrograms per liter (μg/L), and maximum methylene chloride concentrations were 25 μg/L. Three SVOCs—benzyl alcohol, 2-methylphenol, and bis(2-ethylhexyl) phthalate—were detected. Lead, manganese, iron, thallium, and aluminum were detected at concentrations greater than their respective MCLs. The PRA performed for the FS-1 RI eliminated two of the metals— manganese and aluminum—as COCs. Thallium, iron, and lead were retained as a contaminants of potential concern (COPCs). There is no history of thallium use at AOC FS-1, nor are there any reference doses established for thallium in the dissolved state. Consequently, thallium was eliminated as a COC. Iron and lead were retained as COPCs. Toluene concentrations exceeding MCLs were limited to a single well, MW-7. The lead detections above MCLs were limited to the two wells: MW-2 and MW-7. Groundwater collected from wells MW-4A, MW-4A, MW-10A, and MW-10B located approximately 500 feet downgradient of the WAT did not contain organic or inorganic compounds above MCLs.

The resampling of source area groundwater in 1999 to evaluate lead and methylene chloride confirmed that lead was present at levels exceeding the MCL in source area well. Consequently, lead was retained as a COC. Methylene chloride was not detected in wells. This confirms that the methylene chloride was a sampling or laboratory artifact and not a COC. Thallium was detected at concentrations exceeding the MCL in multiple wells. Because of the presence of thallium above the MCL in multiple wells, thallium was reinstated as a COC. Toluene was also detected at levels exceeding the MCL and was retained as a COC.

The only organic compound consistently detected at levels exceeding MCLs in downgradient wells was EDB. The concentrations, ranging from 0.01 μg/L to 7.7 μg/L in CLP analyses, define a coherent plume. Figure 2-5 and 2-5a present the extent of the EDB plume. No inorganic compounds were quantified at levels exceeding MCLs.

Samples collected from the bog with drive points and wells installed by Jacobs exhibited similar concentrations of EDB. EDB ranged from 0.005 to 5.45 μg/L in drive point samples. The maximum level of EDB from Jacobs-installed wells was 10.179 μg/L.

The distribution of EDB in groundwater from the most northern detection to the discharge at the cranberry bogs describes a plume approximately 6,950 feet long, 600 to 1,200 feet wide, and 50 to 100 feet thick. The plume appears to be detached from the source area. The most upgradient detections were in the 600 series fence located downgradient of the source area. The

current downgradient extent of the plume is stable. The plume upwells into the Quashnet River and subsequently forms a portion of that river. The river is an effective hydraulic boundary. Groundwater collected from wells located on the opposite side of the river from the area of upwelling did not contain EDB.

2.7.4 Surface Water

Positive detections of EDB in surface water range from a low of 0.011μg/L in 36SW0012 to a maximum detection of 1.43 μg/L at 36SW0017. Multiple samples did not contain EDB at quantifiable levels. The extent of the zone of upwelling of EDB contamination in the cranberry bogs is difficult to delineate because of the effect of surface water movement across the bog, which acts to commingle zones where EDB may upwell with areas of clean, active surface water movement. Upstream nondetect locations 36SW004 and 36SW0015, which were sampled in August 1997, suggest that most of the EDB-contaminated surface water is entering the bog on the east side of the Quashnet River and its unnamed north-south tributary that enters the bog on the north side. Note that the February 1998 surface water sampling event occurred when the bogs where flooded. The nondetects at locations 36SW0026, 36SW0027, 36SW0028, and 36SW0029, therefore, may not be a representative indication of whether EDB is upwelling into this portion of the cranberry bogs.

As with groundwater, the concentration of inorganic compounds in surface water samples does not exceed MCLs, and exceedances of secondary maximum contaminant levels apply to drinking water aesthetics. Three samples contained aluminum above the federal Ambient Water Quality Criteria for Aquatic Life (AWQC), chronic criteria, but were below AWQC acute criteria. Those samples were 36SW0017, 36SW0019, and 36SW0020. Hardness ranged from a low of 7.96 mg/L $CACO_3$ equivalents to a high of 19.9 milligrams per liter (mg/L) $CACO_3$ equivalents.

2.7.5 Sediment

EDB was detected in only one sample at one location, 36SE0018, at a concentration of 0.075 μg/kg. The seven sediment samples were also analyzed for inorganics. The results were compared to sediment quality guidelines from the Ontario Ministry of Environment and from the National Oceanic and Atmospheric Administration (NOAA) as a preliminary screening. No inorganics exceeded low level guidelines contained in the Ministry document *The Provincial Sediment Quality Guidelines* (Persud et al. 1990). Although the NOAA values were developed for marine and estuary locations, the sediment values from the freshwater bog were compared to the NOAA screening criteria. In the absence of other values, NOAA values can provide a basis to screen sediments for unacceptable contamination. No inorganics exceeded NOAA Effects Range-Low (ER-L). All sediments contained inorganics at concentrations that were, at most, an order of magnitude less than the NOAA ER-L. The two screenings indicate that the levels of inorganics contained in the sediments is acceptable.

Sediments were also tested for total solids and total organic carbon (TOC). Solids ranged from 75.1% to 89.2%. TOC ranged from 121 mg/kg to 8,330 mg/kg.

2.8 REMEDIAL ACTIONS IN PROGRESS

AFCEE began an expedited remedial initiative in the Quashnet bogs during the summer of 1998. As a result of that initiative, Jacobs Engineering Group has completed construction of a Pilot Test at the Quashnet River Bogs in the vicinity of the upwelling of groundwater containing EDB. That pilot study is described in *Quashnet River Bogs Pilot Test* (Jacobs 1999). Actions taken during the pilot study include construction of isolation berms in the bogs, installation of a groundwater extraction system beneath the bogs, construction of a treatment facility for the extracted groundwater, and construction of a reinjection system. The pilot study will operate the described isolation/extraction/treatment/reinjection system for 1 year.

The objective of the pilot test is to evaluate the effectiveness and impact of such a system while simultaneously protecting existing cranberry production operations. This FS incorporates the pilot study in subsequent sections of this study. Aspects of the pilot test are evaluated as potential technologies and process options in Section 6 and are included as elements of remedial action alternatives in Sections 7, 8, and 9.

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3. SUMMARY OF HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT

Risk-based cleanup goals were established to support the development of remedial alternatives that will mitigate potential risks associated with exposures to contamination emanating from AOC FS-1. The risk-based cleanup goals are based on the PRA conclusions reached during the RI. This section summarizes the results of the PRA presented in the Final RI (HAZWRAP 1999) and recommends cleanup goals.

The PRA developed conservative estimates of risk to potential human and ecological receptors based on site-specific assumptions and regulatory guidance presented in the RI. The PRA provides target risk levels for comparison to estimated risks consistent with USEPA's guidelines: the total incremental carcinogenic risk range of 10^{-4} to 10^{-6} and the Hazard Index (HI) target value 1.0. The Massachusetts Contingency Plan (MCP) sets the target carcinogenic risk level at 1×10^{-5} and the HI target noncarcinogenic level at 1.0. The PRA considers incremental carcinogenic risks exceeding 10^{-4} and HIs exceeding 1.0 as requiring further evaluation and risk management decisions.

Risk estimates included in the PRA represent the conservative reasonable maximum for exposure to COPCs. The recommended risk-based cleanup goals are considered to be consistent with the estimated site risks developed based on conservative exposure scenarios.

3.1 HUMAN HEALTH RISK

The purposes of the human health PRA are (1) to characterize risks associated with potential human exposure to contaminated media at AOC FS-1 and within the groundwater plume and upwelling area, (2) to define remedial goals and objectives, and (3) to assist in remedial action decisions. The human health PRA consists of the following components: data evaluation, identification of COPCs, exposure assessment, toxicity assessment, risk characterization, and uncertainty evaluation.

The data sets used in the human health PRA are presented in Table 3.1. (The tables for this document are presented at the end of the text following the figures.) Human health and ecological COPCs for AOC FS-1 and the groundwater plume and upwelling area are presented in Table 3.2. The exposure assessment estimates the frequency and duration of receptor exposure to the contaminant present in the environment by considering multiple exposure pathways. Both current and future potential receptor populations that might come in contact with contaminated media at AOC FS-1 and the groundwater plume and upwelling area identified in the RI are presented in Table 3.3.

Chemical- and site-specific estimates of carcinogenic risks (incremental lifetime cancer risks) and noncarcinogenic HIs were calculated for current and future scenarios. Carcinogenic risk is expressed as a probability of developing cancer as a result of lifetime exposure. For a given chemical and route of exposure, incremental lifetime cancer risk is calculated by multiplying the lifetime average daily dose (ADD) by the cancer slope factor (CSF). USEPA recognizes target incremental lifetime cancer risks as those within the range of 10^{-4} to 10^{-6}. The Massachusetts

Department of Environmental Protection's (MADEP's) MCP target cancer risk level is 1×10^{-5}. An excess lifetime cancer risk of 10^{-4} was used in the PRA to identify the acceptable upper bound. This risk indicates that an individual has a one in ten thousand excess chance of developing cancer as a result of site-related exposure to a carcinogen over a 70-year lifetime under the specific exposure conditions at the site. For exposures to multiple carcinogens, the risk associated with multiple exposures is equivalent to the sum of their individual risks.

To characterize the overall potential for noncarcinogenic effects associated with exposure to multiple chemicals, USEPA has developed an HI approach. This approach assumes that simultaneous subthreshold chronic exposure to multiple chemicals that affect the same target organ are additive and could result in an adverse health effect. The HI is calculated as the sum of the ADD divided by the reference dose (RfD) for each COPC. The term ADD/RfD is referred to as the Hazard Quotient (HQ). The sum of the chemical-specific HQs results in the estimation of an HI. Calculation of HI in excess of 1 indicates the need for further evaluation by individual target organs. If the target-organ-specific HI exceeds 1, then there is a potential for adverse effects.

The cancer and noncancer risks attributable to AOC FS-1 and the groundwater plume and upwelling area are summarized for the reasonable maximum exposure (RME) and central tendency (CT) exposure for surface soil, subsurface soil, groundwater, surface water, and sediment in Table 3.4. COCs with carcinogenic risk $>10^{-6}$ or HQ >1 are also identified in Table 3.4

3.1.1 Carcinogenic Risks

For the current and future on-site worker exposure to soil found at the source area (i.e., WAT and EAT areas), no contaminants detected in soil at AOC FS-1 exceeded the health/risk equivalent concentration (HEC) or surrogate HECs, which indicates risks associated with these compounds are below a risk of 10^{-6}. For this reason, this receptor was not quantitatively evaluated in the risk assessment.

Cancer risks for the current and future cranberry worker are 4×10^{-7} for CT exposure and 3×10^{-6} for RME. This is within USEPA target risk range of 10^{-4} to $10^{-6}$and below the MADEP target risk level of 1×10^{-5}. All RME cancer risk is due to EDB through incidental ingestion, inhalation, and dermal absorption. It is concluded that there are no unacceptable risks to cranberry workers at current COC concentrations.

Cancer risks for current and future recreational youths are 1×10^{-7} for CT exposure and 2×10^{-6} for RME. This is within the USEPA target risk range of 10^{-4} to 10^{-6} and below the MADEP target risk level of 1×10^{-5}. All RME cancer risk is due to EDB through incidental ingestion, inhalation, and dermal absorption. It is concluded that there are no unacceptable risks to recreational youths at current COC concentrations. Cancer risks for current and future adult waders/fish eaters are 4×10^{-6} for CT exposure and 6×10^{-5} for RME. Although this is within the USEPA target risk range of 10^{-4} to 10^{-6}, the RME is greater than the MADEP target risk level of 1×10^{-5}. About 100% of the cancer risk is associated with EDB in surface water and fish. Potential risk to adult waders may exist.

For the future resident exposed to groundwater, the total cancer risk estimates exceed the USEPA target risk range of 10^{-4} to 10^{-6} and the MADEP target risk level of 1×10^{-5}. The primary routes of exposure contributing more than 99% of the risk were the ingestion of groundwater and inhalation of vapors while showering with groundwater. The primary COPCs driving the risk were ethylene dibromide (EDB) (CT exposure, 6.2×10^{-4}; RME, 1.7 × 10-2 for all routes of exposure) and arsenic (CT exposure, 1.3 × 10-5; RME, 3.7 × 10-4 for all routes of exposure). EDB contributes 98% of the risk.

3.1.2 Noncarcinogenic Risks

For the current and future on-site worker exposed to soil found at the source area (i.e., WAT and EAT areas), no contaminants detected in soil at AOC FS-1 exceeded the HEC values, which indicates the HIs associated with these compounds are below 1. For this reason, this receptor was not quantitatively evaluated in the risk assessment.

Total noncancer risks for current and future cranberry worker, recreational youth, and recreational adult/fish eater RME and CT exposures to surface water and sediment are below the USEPA and MADEP target HI of 1.

For the future resident exposed to groundwater, the total noncancer risk or HI estimates are 3 and 20 for CT exposure and RME, respectively. These values are above the regulatory target value of 1. The RME highest organ/tissue-specific HI was for sperm (13.9) (contributed by EDB), which accounted for 60% of the total HI. Other organ/tissue-specific HIs exceeding 1 were 1.4 for chloroform and 2.3 for toluene. The CT highest organ/tissue-specific HI was 2.1 for sperm as a result of EDB that accounted for 76% of the total HI. No other COPCs exceed 1 for the CT.

3.1.3 Lead Evaluation

In the absence of toxicological data (CSF and RfD) for lead, lead concentrations found in surface soil and subsurface soil samples at AOC FS-1 and in groundwater, surface water, and sediment from the groundwater plume and upwelling area were compared to USEPA action levels for drinking water and the MADEP standard for soil of 15 ppb and 300 ppm, respectively. Both surface soil and subsurface soil lead concentrations were below USEPA action levels. The surface water and sediment lead maximum concentrations (2.02 ppb and 8.9 ppm, respectively) were below USEPA action levels. The mean lead concentration found in groundwater (8.52 ppb) was below the drinking water standard; the maximum concentration (159.0 ppb) exceeded the USEPA standard of 15 ppb.

To further evaluate potential health effects from lead exposures, blood lead concentrations have been accepted as the best measure of exposure. USEPA has developed an uptake/biokinetic model [the Integrated Exposure Uptake Biokinetic (IEUBK) Model] to assess chronic, noncancer exposure of children to lead. Version 0.99d of the model was used during the PRA to evaluate possible future exposure of child residents to lead from groundwater (USEPA 1994). The IEUBK Model was run for lead using the mean and maximum concentrations found in groundwater within the AOC FS-1 groundwater plume and upwelling area for the age range of 0 to 6 years. USEPA and MADEP, Office of Research and Standards, have accepted the estimate

that no more than 5% of the exposed child population would be expected to have blood lead levels above 10 micrograms per deciliter (μg/dL) as the cutoff value.

The RI presents the results of the IEUBK Model used to estimate blood lead levels in children. Use of the mean lead concentration of 8.52 μg/L resulted in a prediction of less than 5% of the children (at 0 to 6 years of age) would have blood levels above 10 μg/dL. The 159 μg/L maximum concentration resulted in a prediction that greater than 5% of the children would have a blood lead level above 10 μg/dL. Based on the lead uptake/biokinetic model, the probability of risk from lead exposure exceeds the USEPA target of 5%. Approximately 67% of the children exposed to the maximum concentrations in groundwater would be expected to have blood lead levels greater than 10 μg/dL. These results indicate the maximum concentration of lead in the groundwater could pose a potential health concern for children.

3.1.4 Thallium

Thallium exceeding the MCL was detected within the source area wells. There are no toxicity values for the soluble salts of thallium, and no risk assessment was performed. No further analysis of thallium will be conducted because thallium detections are limited to within the source area, and the land use for this area will remain the same. No groundwater drinking wells will be placed in this area. Therefore, exposure to thallium through residential uses of groundwater is unlikely.

3.2 ECOLOGICAL PRELIMINARY RISK ASSESSMENT

The ecological PRA conducted for AOC FS-1 and the groundwater plume and upwelling area were in accordance with the current guidance documents and toxicological data. Evaluated in the ecological PRA were potential risks to terrestrial receptors at AOC FS-1 and to semiaquatic and aquatic risks within the groundwater plume and upwelling area. The ecological PRA evaluation used exposure assessment modeling to estimate potential risks to ecological receptors only for those compounds considered of ecological concern (i.e., COPCs). The PRA estimated potential intake rates via potential exposure pathways for selected receptor species using both the maximum and mean concentrations of the selected COPCs. These estimated intakes were compared to acceptable intake rates or doses to determine if a potential threat to ecological receptors may exist at the site.

The data sets used in the ecological PRA are in Table 3.1. The ecological COPCs are identified in Table 3.2. The selected receptor species are presented in Table 3.5 by habitat. Representative receptor species were chosen because (1) they may be present at AOC FS-1 or within the groundwater plume and upwelling area (HAZWRAP 1999), (2) their feeding habits (i.e., predominantly herbivorous, omnivorous, or carnivorous) are representative of the feeding habits of species typically found in the habitat available at the site, and (3) these species are among those that have been chosen for a conservative evaluation of ecological risks at MMR (HAZWRAP 1994). It is assumed that each of the receptor species is representative of other species within a trophic level present at AOC FS-1 and the groundwater plume and upwelling area.

3.2.1 Terrestrial Receptors at AOC FS -1

Although AOC FS-1 presents limited habitat for fauna under current conditions, some foraging activities may occur at the site. This area may provide suitable foraging habitat under future scenarios.

Five species considered representative of those animals that may occur at AOC FS-1 currently or in the future were selected because they represent various trophic levels including omnivorous mammals, herbivorous mammals, insectivorous mammals, omnivorous birds, and carnivorous birds. The five receptor species are red fox (*Vulpes vulpes*), white-footed mouse (*Peromyscus leucopus*), short-tailed shrew (*Blarina brevicamda*), cardinal (*Cardinalis cardinalis*), and grasshopper sparrow (*Ammodranus savannarum*). Terrestrial plants were also identified as an ecological receptor group at AOC FS-1 and evaluated for phytotoxicity.

3.2.2 Aquatic and Semiaquatic Receptors for the Groundwater Plume and Upwelling Area

The Handy Bog and the Quashnet River within the groundwater plume and upwelling area provide a permanent aquatic habitat and semiaquatic habitat under current and future conditions. Potential risks to aquatic vertebrate and invertebrate receptors from exposure to analytes detected in surface water and sediment were evaluated by directly comparing maximum and mean chemical concentrations detected in these media to aquatic receptor benchmarks from the USEPA Ecotox Thresholds software, Eco updates, and other source as noted in Appendix H of the RI.

Eight species considered representative of aquatic and semiaquatic species that may occur within the groundwater plume and upwelling area were selected according to the USEPA guidance (USEPA 1997). Chemical exposures for some of these species are estimated in Appendix H of the RI. The eight species include one amphibian, one reptile, one fish, two medium-size mammals, and three birds. The eight receptor species are bull frog (*Rana catesbeiana*), eastern box turtle (*Terrapene carolina*), brook trout (*Salvelinus fontinalis*), muskrat (*Ondatra zibethicus*), raccoon (*Procyon lotor*), mallard (*Anas platyrhynchos*), black-crowned night heron (*Nycticorax nycticorax*), and osprey (*Pandion haliaetus)*.

The purpose of the ecological risk assessment was to identify the potential adverse effects to receptors associated with the identified COPCs and to evaluate the relationship between the concentration to which a receptor is exposed and the potential for adverse ecological effects.

The results of an ecological assessment describe the relationship between exposure to contamination and particular adverse ecological effects. Assessment endpoints were chosen and evaluated to determine the presence or absence of these adverse ecological effects. The following assessment endpoints were used for evaluating the potential impacts associated with exposure to the identified COPCs in the ecological PRA: (1) a reduction in population abundance or reproduction of local vertebrate or plant groups and (2) any toxic effect on an individual of a federally or state-protected species sufficient to impair its survivorship or reproduction.

Benchmark values presented in the RI were obtained from the most current toxicological literature and represent conservative contaminant threshold doses designed to be protective of ecological receptors. Thresholds are concentrations below which adverse effects are considered unlikely. These benchmark values were compared to the estimated exposure concentration or doses to estimate the likelihood of adverse ecological effects.

The risk to terrestrial, semiaquatic, and aquatic receptors potentially exposed to contamination in surface soil at AOC FS-1 and the surface water and sediment within the groundwater plume and upwelling area were characterized. The exposure information was compared with the ecological effects information to provide the basis for the risk characterization.

3.2.3 AOC FS-1 Surface Soil

Evaluations of risk to terrestrial vertebrate receptors exposed to surface soil at AOC FS-1 were based on risks associated with terrestrial food chains. Food chain receptor risk were not calculated for the red fox and the northern cardinal because, during the selection of COPCs, no analyte concentrations exceeded the screening value for these receptors. Results of the risk analysis under the maximum concentration exposure scenario assumptions include findings of total HIs at or below 1 for the white-footed mouse, short-tailed shrew, and grasshopper sparrow. Table 3.6 presents a summary of the risk characterization for terrestrial model receptors exposed to surface soil.

Evaluations of risk to terrestrial plants at AOC FS-1 was based on the maximum and mean detected concentrations of COPCs in the surface soil compared to benchmark levels known or predicted to be toxic to vegetation. The HIs at and below 1 for maximum and mean concentrations indicates that the soil at AOC FS-1 is not likely to present a significant risk to the terrestrial species. Table 3.6 presents a summary of the HIs for terrestrial vegetation exposed to surface soil.

3.2.4 Groundwater Plume and Upwelling Area Sediment and Surface Water

Evaluation of risks to semiaquatic vertebrate receptors exposed to sediment and surface water within the groundwater plume and upwelling area was based on risks associated with aquatic food chains. Food chain receptor risks were not evaluated for the mallard duck because, during the selection of COPCs, no analyte concentrations exceeded the screening values for this receptor.

Risks to potential aquatic receptors were estimated by comparing maximum and mean detected concentrations of COPCs to Ecotox Threshold values, which use AWQC and other guidelines for sediment and surface water to calculate HIs. . The maximum HI for surface water was 18 and the mean HI was 8. The maximum HI indicates that the no observed adverse effects limit (NOAEL) benchmark has been exceeded; however, the maximum concentration compared to the lowest observed adverse effects level (LOAEL) benchmark would barely exceed 1, and the average concentration would not exceed the LOAEL benchmark. The maximum concentrations of aluminum, barium, and iron contributed the most to the aquatic risk. Although these analytes are greater than the estimated background levels, they are not believed to be site related, and they

could be indigenous to this type environment. Therefore, although comparison of media concentrations to NOAEL benchmarks suggests a potential effect, significant effects to the assessment endpoint (reproduction and population) are not expected. Sediment in the groundwater plume and upwelling area had an HI less than 1.0 for aquatic receptors. To further evaluate the potential adverse effects to fish and amphibians from surface water and sediment contamination, the fish benchmarks (Suter and Mabry 1994) were compared to the maximum concentration exposure scenario for the brook trout and the bull frog. This comparison resulted in a total HI of 2 from exposure to inorganics. Therefore, although comparison of media concentrations to NOAEL benchmarks suggests a potential effect, significant effects to the assessment endpoint (reproduction and population) are not expected.

Results of the risk analysis for the semiaquatic receptors under the maximum concentration exposure scenario assumptions include findings of total HIs below 1 for the eastern box turtle, muskrat, raccoon, black-crowned night heron, and osprey. The results of the ecological PRA indicate that adverse effects from contamination at the AOC FS-1 and the groundwater plume and upwelling area are not likely. Table 3.6 presents a summary of the risk characterization for semiaquatic receptors exposed to groundwater plume and upwelling area sediment and surface water.

3.3 RECOMMENDATIONS AND CLEANUP GOALS

Based on the RI data collected and evaluated and on the human health and ecological PRAs, no further action or investigation was recommended for the AOC FS-1 soils. Further actions are recommended for the groundwater plume and upwelling area to address potential human health concerns. Because of the potential human health risks associated with residential groundwater exposures and groundwater impacts on surface water and fish contaminant levels, an FS was recommended. The primary contaminants of concern are toluene, EDB, thallium, and lead. The recommended preliminary remediation goals for the COCs in the groundwater upwelling plume emanating from FS-1 are USEPA MCLs and the Massachusetts maximum contaminant levels (MMCLs) and are presented in Table 3.7.

If active remedial alternatives are chosen, the following steps will be taken.

- Remediate the aquifer to federal and state drinking water standards (MCLs).
- When MCLs are achieved and before the system is shut off, perform a risk assessment to determine if unacceptable ecological or human health risks remain. If unacceptable risks are present, continue system operation and/or pursue additional measures as required to achieve acceptable risks.
- After acceptable risks have been achieved, evaluate the technical and economic feasibility of additional remediation to approach or achieve background concentrations.

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4. APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS IDENTIFICATION

Section 120 of the Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA) provides requirements for the remediation of media containing hazardous constituents released from federal facilities. CERCLA also states that each department, agency, and federal facility is subject to, and must comply with, the act. Therefore, all guidelines, rules, regulations, and criteria carried out under CERCLA, including the National Contingency Plan (NCP), are applicable to federal facilities. CERCLA authorizes USEPA to include sites owned or operated by other federal agencies on the National Priorities List (NPL). MMR was added to the NPL and is currently managed under the IRP section of the Department of Defense Environmental Restoration Program.

CERCLA, the Superfund Amendments and Reauthorization Act, and NCP require that ARARs be identified during the development of remedial alternatives. ARARs are federal and state human health- and environmental-based requirements and guidelines used (1) to determine the appropriate levels of site cleanup, (2) to define and formulate remedial action alternatives, and (3) to govern implementation and operation of the selected remedial action.

4.1 DEFINITION OF ARARs

The NCP defines two ARARs components: (1) applicable requirements and (2) relevant and appropriate requirements. The NCP also identifies a third category of guidance: information to be considered. These components are defined below.

4.1.1 Applicable Requirements

Applicable requirements include federal and state cleanup standards, controls, or environmental legislation that "specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance" (40 CFR Part 300.4).

4.1.2 Relevant and Appropriate Requirements

Relevant and appropriate requirements include "federal and state requirements that are not applicable as defined above but may address problems or situations sufficiently similar to those encountered at the site," and "their use is well suited to the site" (40 CFR Part 300.4). Relevant and appropriate requirements have the same weight and consideration as applicable requirements. The term relevant was included so that a requirement initially screened as nonapplicable because of jurisdictional restrictions could be reconsidered and, if appropriate, included as an ARAR for the site

4.1.3 To Be Considered

Other information to be considered includes federal and state advisories or guidelines that are not legally binding and do not have the status of potential ARARs. However, if no specific

ARARs for a chemical or site condition exist, or if existing ARARs are not deemed sufficiently protective, then guidance or advisory criteria should be identified and used to ensure human health and environmental protection.

4.2 IDENTIFICATION OF ARARs

As defined, federal and state requirements must be considered for identification of site-specific ARARs. Federal and state requirements include ARARs that are:

- chemical specific (i.e., govern the level or extent of site remediation in relation to a specific contaminant),
- location specific (i.e., pertain to existing site features), or
- action specific (i.e., pertain to proposed site remedies and govern implementation of the selected site remedy).

4.2.1 Chemical-Specific ARARs

Chemical-specific ARARs are usually health- or risk-based standards that limit contaminant concentrations found in the environment. These ARARs govern the extent of site remediation by providing cleanup levels or a basis for calculating cleanup levels. For example, drinking water standards may provide necessary cleanup goals for a site with contaminated groundwater.

4.2.2 Location-Specific ARARs

Location-specific ARARs place restrictions on contaminant concentrations or remedial activities based solely on site setting or location (e.g., within or adjacent to wetlands, floodplains, existing landfills, disposal areas, and places of historical or archeological significance).

4.2.3 Action-Specific ARARs

Action-specific requirements are usually technology- or activity-based requirements or limitations on actions taken with respect to hazardous substances. After remedial alternatives are developed, action-specific ARARs pertaining to proposed site remedies provide a basis for assessing the feasibility and effectiveness of the remedies. For example, action-specific ARARs may include hazardous waste transportation and handling requirements, air and water emissions standards, and Resource Conservation and Recovery Act (RCRA) landfilling requirements.

The identification of ARARs is an iterative process to be considered throughout the remedial response. The list of identified requirements and their relevance may change as more information is obtained, the preferred alternative is chosen, and the design and approach to remediation becomes more refined.

5. BASIS FOR SITE REMEDIATION

The potential risk to human health receptors from exposure to groundwater and surface water was identified during the AOC FS-1 RI. The USEPA MCLs and the Massachusetts maximum contaminant levels (MMCLs) define the groundwater concentrations protective of human health. For those remediation options requiring groundwater treatment based on risk assessment, the cleanup goal will be restoration to beneficial use if technically and economically possible. The ARARs evaluation presented in Section 4 did not identify any additional applicable cleanup goals for AOC FS-1.

RAOs are the basis for identification of technologies for site remediation. Section 5.1 identifies the RAOs for the above-referenced media of concern at AOC FS-1. Section 5.2 identifies the appropriate area within AOC FS-1 where remediation is required. Section 5.3 presents the general response actions considered in this FS.

5.1 REMEDIAL ACTION OBJECTIVES

RAOs are site-specific, qualitative, initial cleanup objectives established on the basis of the nature and extent of the contamination, the resources currently or potentially threatened, and the potential for human and environmental exposure. For AOC FS-1, RAOs were formulated for the groundwater plume and surface water in the Quashnet River bogs identified during the AOC FS-1 RI (HAZWRAP 1999). The RAOs are based on the environmental problems defined in the environmental contamination assessment and PRA developed in the RI and on ARARs analysis. RAOs provide the framework for development of the general response actions and are formulated to achieve the overall goal of protecting human health and the environment (USEPA 1988a).

The following RAOs were identified for AOC FS-1.

- Prevent or reduce exposure to groundwater COCs exceeding cleanup standards in groundwater.
- Restore the aquifer to beneficial uses within a reasonable time frame.
- Prevent or reduce worker, recreational youth, and adult wader contact with Quashnet River water containing unacceptable concentrations of EDB and ingestion of fish exposed to Quashnet River water containing unacceptable concentrations of EDB.

If active remedial alternatives are chosen, the following steps will be taken.

- Remediate the downgradient aquifer to federal and state drinking water standards (MCLs)..
- When MCLs are achieved and before the system is shut off, perform a risk assessment to determine if unacceptable ecological or human health risks remain. If unacceptable risks are present, continue system operation and/or pursue additional measures as required to achieve acceptable risks.

- After acceptable risks have been achieved, evaluate the technical and economic feasibility of additional remediation to approach or achieve background concentrations.

This three-step process has been agreed to solely at MMR due to unique circumstances presented by the location of the FS-1 plume within the sole-source aquifer of Upper Cape Cod. The selection of COCs to which the RAOs apply is contained in Tale 5-1. The COCs are (1) EDB for the downgradient impacted groundwater and surface water and (2) toluene, lead, and thallium for the source area groundwater.

5.2 AREA AND VOLUMES REQUIRING REMEDIATION

The distribution of EDB in groundwater from the most northern detection to the discharge at the cranberry bogs describes a plume approximately 6,950 feet long, 600 to 1,200 feet wide, and 50 to 100 feet thick. The estimated volume of contaminated water contained in that plume is approximately 121 million gallons. Detections of lead and toluene are limited to within several hundred feet of the source area.

5.3 GENERAL RESPONSE ACTIONS

In accordance with the NCP (40 CFR Part 300) and CERCLA guidance (USEPA 1988a), a preliminary list of alternatives should present a range of viable options. This list of alternatives should include actions that address the response objectives and significantly reduce the toxicity, mobility, and/or volume of the media of concern. At least one option should include little or no treatment. In accordance with the above-referenced guidance, a No Action alternative is considered.

The following general response actions have been identified to address groundwater and surface water contamination related to AOC FS-1.

- No Action,
- Institutional Controls,
- Extraction,
- Ex Situ Treatment,
- In Situ Treatment,
- Discharge, and
- Containment.

6. REMEDIAL TECHNOLOGY IDENTIFICATION, SCREENING, AND PROCESS EVALUATION

This section identifies and evaluates remedial technologies and process options that are capable of achieving the RAOs presented in Section 5.2 for AOC FS-1. The identification of the potential remedial technologies and process options was based on the seven general response actions presented in Section 5.3 and on their ability to satisfy the RAOs. The identified general response actions are:

- No Action,
- Institutional Controls,
- Extraction,
- Ex Situ Treatment,
- In Situ Treatment,
- Discharge, and
- Containment.

Following identification, the technologies and process options were screened to evaluate applicability to the COCs, media of concern, and site conditions. These potential remedial technologies and process options will be developed into remedial action alternatives in Section 7. The identification and screening of technologies is discussed in Section 6.1, and the evaluation of technologies and process options is discussed in Section 6.2.

6.1 TECHNOLOGY IDENTIFICATION

MMR Remedial Technology Evaluation and Applicable or Relevant and Appropriate Requirements Handbook (HAZWRAP 1989) and the USEPA/AFCEE *Remedial Technologies Screening Matrix and Reference Guide* (USEPA 1994) were used to identify technologies for each of the general response actions presented in Section 5.3: No Action, Institutional Action, In Situ Treatment, Extraction/Treatment, and Containment. Technologies were selected for this initial screening based on their potential to satisfy the RAOs (as presented in Section 5) by reducing the exposure to COCs. For each technology, specific process options were considered and selected for evaluation under the screening process. Table 6.1 presents the remedial technologies identified and screened for groundwater.

6.2 PROCESS OPTION EVALUATION

Each of the identified technologies and process options was screened using the criteria defined below. The criterion addresses the technical and administrative feasibility of employing the technology and/or process option at AOC FS-1; emphasis is placed on the following aspects:

- effectiveness,
- implementability, and
- cost.

If a technology or process option did not meet the requirements of the criteria, then the technology and/or process option was eliminated from further evaluation. The technologies and process options that did satisfy the requirements of the criteria were retained for the development of remedial alternatives.

6.3 REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER

The following remedial technologies and process options were selected under the general response actions identified for contaminated groundwater and surface water related to AOC FS-1.

6.3.1 No Action

There are no remedial technologies and process options required under this general response action. Under this option, an AOC continues to exist in its current condition with no attempt to either prevent or minimize the exposure of receptors to site COCs. This option was retained for further consideration in accordance with the requirements of CERCLA (USEPA 1988b).

6.3.2 Institutional Action

This general response action consists of activities to monitor site conditions and contaminants and provide controls to partially limit contact between potential receptors and site contamination.

6.3.2.1 Monitoring

This process option involves periodic groundwater sampling and observation of AOC conditions to track the migration of contaminants. This process option, which includes groundwater monitoring and site inspection, was retained for further consideration to monitor groundwater quality and AOC conditions and to evaluate the effectiveness of any remedial action undertaken at AOC FS-1.

6.3.2.2 Access Restrictions

This process option provides a means of controlling physical contact between potential human receptors and site contaminants at the AOC. This level of control will be achieved with the legal controls in an attempt to limit future groundwater use in the vicinity of identified groundwater contamination. At FS-1, the authority for such actions is divided based on whether the contaminated groundwater is located on the base or off the base. For that portion of the plume located on the base, groundwater associated with the FS-1 plume is not used. Residents and workers on the base obtain drinking water from the base water supply system. All construction projects, including water supply wells, require written approval from the Base Civil Engineer. The Base Civil Engineer will have the responsibility of authorizing water use from the on-base portion of the plume. Additionally, if new wells are drilled on the base, DEP must authorize that construction. For that portion of the plume located off the base, the Town of Mashpee has the authority to restrict groundwater use. The Town of Mashpee has issued a

"Moratorium on Groundwater Wells," which restricts the use and construction of wells in documented or anticipated areas of groundwater contamination. The water cannot be used for any purpose. A copy of the moratorium is contained in Appendix F. The Mashpee Board of Health is responsible for posting the cranberry bogs and Quashnet River in the area of FS-1 upwelling. Mashpee has posted the area. This process option, which includes zoning restrictions and general access restrictions, was retained for further consideration as a way to minimize exposure to site contaminants.

6.3.2.3 Potable Water Supply

This process option provides a means of meeting local public need for a potable water supply source. A potable water supply would be provided to those individuals with private wells in the AOC if it was determined that their potable water supply was in jeopardy. Potable water supply was eliminated because of the absence of dwellings in the plume area.

6.3.3 Natural Attenuation

This option provides a means of eliminating contamination. Documented naturally occurring mechanisms would reduce contamination. This process is ongoing in the source area. The absence of readily degraded compounds and low dissolved oxygen quantified in the source area indicates biodegradation is occurring on compounds amenable to biodegradation. However, biodegradation is not generally considered a mechanism for EDB contamination attenuation. Lead is limited to the immediate source area. Given that the lead is restricted to the source area, it can be inferred that the lead is attenuating naturally. The discharge of the plume to the Quashnet River is also a natural attenuation mechanism, but simple discharge to the river does not comply with USEPA preferences for attenuation mechanisms that degrade contaminants. Because discharge to the river does not reduce the toxicity, volume, and/or mobility of the EDB, natural attenuation was eliminated for EDB. Natural attenuation was retained for the COCs in the source area.

6.3.4 Extraction

This general response action involves the removal of groundwater from the aquifer as a part of an alternative that would cause a reduction in contamination.

6.3.4.1 Interceptor Trenches

Trenches, drains, and piping could be used to passively collect contaminated groundwater. However, the only area where this is feasible is at the extreme toe of the plume. Review of groundwater flow patterns, especially the vertical flows present at the toe of the plume, indicate that a trench would not be as effective or flexible as a well field. This option was eliminated.

6.3.4.2 Wells

Vertical wells may be arranged and pumped in a manner that preferentially extracts contaminated groundwater. This option may include large-diameter wells pumping at high rates,

a network of smaller wells pumping at lower rates, or idealized combinations of large and small wells arranged to most effectively extract groundwater. The process option has been retained.

6.3.4.3 Directional Wells

Some permutations of this process option are applicable to AOC FS-1. The retained options include deep directional drilling for the extraction of groundwater and the injection of fluids and shallow directional wells for extraction and/or reinjection of groundwater in the Quashnet River bog area.

6.3.5 Treatment Technologies

This general response action involves various process options for the treatment of groundwater as part of a remedial alternative. The options include no treatment, ex situ treatments, and in situ treatments.

6.3.5.1 Ex Situ Treatment

This general response action involves the treatment of groundwater after that groundwater has been extracted. Ex situ treatment is the most commonly used general response for groundwater.

6.3.5.1.1 Air Stripping

Air stripping involves forcing air through contaminated water. Volatile compounds are transferred from the dissolved phase to a gaseous phase. The technology is common. Off-gas may require additional treatment. However, EDB has a Henry's constant that does not favor complete stripping of EDB in reasonably sized stripping systems. The option was eliminated.

6.3.5.1.2 Filtration

In this process option, filters are used to remove particles before other treatment. It is a standard process. However, experience at MMR indicates that particulate loading is not an issue at MMR. The process option was eliminated.

6.3.5.1.3 Activated Carbon Adsorption

This process option uses the preferential adsorption of organic compounds onto an organic substrate. It has been successfully used at MMR in association with EDB. Additionally, granular activated carbon (GAC) will adsorb limited levels of metals. This option was retained.

6.3.5.1.4 Ultraviolet/Oxidation

Ultraviolet (UV)/oxidation uses the energy of UV radiation to break bonds in hydrocarbons. Oxidation is often used in conjunction with UV radiation to augment the process option. Typical costs for this option are higher than for other effective, implementable options (GAC). This option was eliminated due to high cost.

6.3.5.1.5 Ultraviolet/Reduction

UV/reduction uses the energy of UV radiation to break bonds in hydrocarbons. Reduction has been used in conjunction with UV radiation to augment the process option. Proprietary catalysts are used as reducing agents. Typical costs for this option are higher than for other effective, implementable options (GAC). This option was <u>eliminated</u> due to high cost.

6.3.5.1.6 Reverse Osmosis

This process option removes primarily inorganic constituents from groundwater during passage of water through a membrane. It was <u>eliminated</u> from consideration. Though the metal lead is a COC in the risk assessment, detections of those elements are sporadic and of insufficient concentrations to warrant specific inclusion of reverse osmosis as a process option.

6.3.5.1.7 Resin Adsorption/Ion Exchange

Resin absorption uses engineered resin to selectively remove organic compounds from water. Ion exchange is a similar technology except that inorganic ions are removed. Typical costs for this option are higher than for other effective, implementable options (GAC). This option was <u>eliminated</u> due to high cost.

6.3.5.2 In Situ Treatment

In situ treatments include a range of process options used to remediate groundwater. The methods are often preferable to extraction and treatment because the methods do not disturb flow regimes as significantly.

6.3.5.2.1 Reactive Wall

Reactive walls involve the excavation of a trench or construction of a funnel-and gate-system. A catalytic medium is placed in the trench or gates of the funnel and gate. Groundwater encountering the catalytic materials is broken down into component compounds. A trench system is not applicable because the only locations at which the system could be installed are not protective of human health. The funnel-and-gate system is not appropriate because experience at MMR has shown that it is not possible to install the system at the required depths. Reactive walls have been <u>eliminated</u> from consideration.

6.3.5.2.2 Biologic Treatment

This option involves supplementing naturally occurring organisms with nutrients. The process option was <u>eliminated</u> because the technology is incapable of decreasing COCs to acceptable levels.

6.3.5.2.3 Co-metabolic Enhancement

Co-metabolic enhancement is accomplished by injecting methane and nutrients into the zone of contamination. The methane is used by existing bacteria or introduces bacteria as a primary

food source. The halogenated compounds are used secondarily by the methanogenic bacteria. It is questionable if the technology can remediate the COCs to acceptable levels. The explosive nature of methane and questionable availability to receive permitting is also a problem. Because of these issues, co-metabolic enhancement was eliminated.

6.3.5.2.4 Air Sparging

Air sparging is an option in which air is injected into the zone of contamination. Volatile compounds partition into the air and are transported out of groundwater. However, because the contaminated groundwater is covered by approximately 100 feet of clean groundwater, it is possible that the clean groundwater would be contaminated by COCs repartitioning to that water. Because of the possible spreading of contamination, this option was eliminated.

6.3.5.2.5 Peroxide/Iron Injection

A peroxide/iron solution is injected into the zones of contamination and oxidizes the COCs. The daughter products of the oxidation are bromine and carbon dioxide. The system is essentially a liquid reaction wall. The oxidizing agents will also travel with groundwater and continue to oxidize contaminants outside the zone of injection. The solution must be engineered to account for dissipation of the oxidizing agent before discharge. Regulatory acceptance may be difficult; cleanup levels of 0.02 μg/kg may not be achieved. The option was eliminated based on the questionable ability of the technology to achieve RAOs.

6.3.5.2.6 Recirculating Wells

A vertical groundwater circulation cell is established by extraction and reinjection of water in the aquifer with a single well. Air is used to lift water in the well. As the air lifts the water, it also strips VOCs. The technology is dependent on the ratio of vertical conductivity to horizontal conductivity. If horizontal conductivity exceeds vertical conductivity by a sufficient amount, the circulation cells will be established. In zones of high K values, the well may be unable to circulate enough water to create a recirculation cell. It is difficult to determine the effectiveness of a cell. Additionally, the contaminant of primary concern (EDB) is not readily stripped. Because of the uncertainty of the process and limited effectiveness, it was eliminated.

6.3.6 Discharge

Subsequent to ex situ treatment, water may need to be reintroduced back into the aquifer or surface water.

6.3.6.1 Groundwater Reinjection

In this option, treated groundwater is reinjected into the aquifer using wells or infiltration galleries. Injection points are engineered to augment aquifer cleanup and to maintain hydraulic heads. This option was retained.

6.3.6.2 Surface Water Discharge

This option involves discharging treated groundwater to surface water bodies. It was retained.

6.3.7 Containment

This option involves construction of systems that will prevent contaminated media from moving into areas that are not contaminated.

6.3.7.1 Berms

This option involves the construction of earthen structures located on the perimeter of bogs contaminated with EDB. Surface water from the contaminated bogs is prevented from flowing into other bogs or the Quashnet River. It was retained.

6.4 INTRODUCTION TO REMEDIAL ALTERNATIVE DEVELOPMENT

The technology types and process options carried forward from the initial screening are considered in the development of remedial alternatives. These remedial alternatives contain either individual process options or a combination of technologies and/or process options capable of achieving the RAOs and were considered appropriate for AOC FS-1 based on effectiveness, implementability, and associated cost to perform the remedial activity. The development of remedial alternatives to mitigate the contamination at AOC FS-1 is presented in Section 7.

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7. DEVELOPMENT AND SCREENING OF REMEDIAL ACTION ALTERNATIVES

Remedial alternatives were developed to satisfy the RAOs for AOC FS-1 presented in Section 5. These remedial alternatives are assembled from technologies and process options that were deemed in Section 6 to be implementable at the AOC and to satisfy, in part or as a whole, the RAOs. The remedial alternatives for the AOC are screened based on three criteria: effectiveness, implementability, and cost in accordance with CERCLA (USEPA 1988). The identification and development of remedial alternatives is discussed in Section 7.1; the screening of these remedial alternatives is discussed in Section 7.2.

7.1 DEVELOPMENT OF ALTERNATIVES

Five remedial alternatives were developed from technologies and process options that were determined in Section 6 to have the capacity of being technically and administratively implemented at the AOC, to satisfy in part or as a whole the short- and long-term requirements of the RAOs, and to be cost-effective. The five alternatives contain an individual or a combination of technology(ies) and/or process option(s) tailored to achieve the RAOs for contaminated groundwater and surface water associated with AOC FS-1.

As part of an expedited cleanup initiative, AFCEE has developed a pilot test involving groundwater extraction and treatment at the Quashnet River bogs where the leading edge of the EDB groundwater plume is discharging. The pilot test is described in *Quashnet River Bogs Pilot Test* (Jacobs 1999). Leading edge extraction involves shallow interceptor wells and one deep groundwater extraction well, treatment by GAC, and discharge by reinjection and surface water discharge. Aspects of the pilot test are evaluated as potential technologies and process options. This FS incorporates the pilot test as portions of Alternatives 2B and 3B.

Alternative 1:	No Action
Alternative 2:	Limited Action
Alternative 2B:	Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge
Alternative 3:	Axial Well Extraction, Treatment, and Reinjection/Discharge
Alternative 3B:	Axial and Leading Edge Extraction, Treatment, and Reinjection/Discharge

Descriptions of each remedial alternative are provided in the following section; a summary list of components that make up each remedial alternative is provided in Table 7.1.

7.2 SCREENING OF ALTERNATIVES

The alternatives were screened to determine their applicability to achieve the RAOs for contaminated groundwater at AOC FS-1. To accomplish this task, the screening process evaluated factors that influenced the remedial action alternative application at the AOC: effectiveness, implementability, and cost. If an alternative did not meet the requirements of each

of these three criteria, then the alternative was eliminated from further consideration. The remedial action alternatives that did satisfy the requirements of the three criteria were retained for further development. A detailed evaluation of the alternatives appears in Section 8.

Each of the identified remedial action alternatives was screened using the criteria defined below as established in the NCP [40 CFR 300.450(e)(7)] and in Section 4.3.2 of *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA 1988a).

Effectiveness This criterion addresses the degree to which an alternative achieves the RAOs; how quickly the alternative achieves the RAOs; whether the alternative reduces toxicity, mobility, and/or volume through treatment; and how the short-term impacts are minimized. Alternatives that do not provide adequate protection of the receptors or that do not adequately minimize the potential effect of contamination on the groundwater and surface water were eliminated from further consideration. In addition, alternatives that are relatively less effective in comparison with the other alternatives were also eliminated.

Effectiveness is divided into short-term and long-term effectiveness to illustrate the alternative's ability to address the identified contamination at the AOC during implementation of the remedial response(s) and after the remedial response(s) have been implemented. The evaluation for short-term and long-term effectiveness is based on the following definitions:

- Short-Term Effectiveness addresses the impact of the alternative on human health and the environment during construction and implementation of the remedial response(s).
- Long-Term Effectiveness and Permanence addresses the impact of the alternative on human health and the environment after completion of the remedial response(s).

The effectiveness comparison considered whether the alternatives will be of high, moderate, or limited effectiveness in minimizing impact to human health and the environment during implementation and operation of the technologies and process options as well as the permanence of the response action(s) in reducing the risks to human health and the environment. The evaluation of effectiveness was based on experience and engineering judgment.

A groundwater model was developed and used as the primary tool for determining effectiveness. That model, created by Advanced Technology Systems, Inc., is contained as Appendix B. Model parameters are discussed in the modeling report and conformed to accepted modeling standards. A flow model that calculates groundwater flow and a particle tracking model capable of tracking particles carried in the groundwater flow were developed. Twenty-one scenarios were modeled. Table 7-1 presents the number of wells, the pumping rates, and percent of total mass captured for the 21 modeled scenarios. Model graphics include groundwater contours, particle tracks, fate of particles graphs, and mass capture with average groundwater concentration graphs. Interpretation of the results is contained in the Section 8 effectiveness evaluations for each alternative. The most effective scenarios and well configurations were chosen for inclusion in the FS. Alternative configurations may be developed and implemented. The well field configurations developed for this FS may be altered during the design phase of remedial action at FS-1.

The model was developed in three stages. Stage 1 modeling was used to simulate various in-plume remediation alternatives. Seven simulations were conducted: one no-action simulation and six active pumping simulations. The in-plume pumping simulations included (1) wells along the axis of the plume from the most upgradient area of contamination to the Quashnet River bogs (axial fence configuration) and simulations (2) using wells placed at right angles to the plume movement (equipotential fences configuration). Those simulations using wells at right angles to plume movement included well fences intersecting the plume at several locations. Results of the first phase indicated that placing wells and extracting contaminated groundwater along the axis of the plume (axial fences) was more effective than extracting contaminated groundwater at several fences intersecting the plume (equipotential fences). The axial fences extracted more contamination in less time than did the equipotential fences. The axial fences are more effective than the equipotential fences because the flowlines to the wells are shorter in the axial fence configurations. The axial fence configuration was chosen for the conceptual design because of effectiveness. All subsequent evaluations of in-plume groundwater extraction alternatives in this FS use the axial well configuration for evaluating effectiveness and cost.

Stage 2 modeling simulated the effectiveness of a bog-specific remediation alternative. The simulations tested six designs. All designs included a single, large-diameter well (EW-05) north of the bogs, well points in the bog, modifications to the well points, reinjection, and surface water discharge. The most effective configuration was carried forward into Stage 3 modeling. Stage 3 modeling combined the axial in-plume extraction scenarios with the bog-specific remediation alternative and included the potential public supply well P-11.

Implementability This criterion evaluates the technical feasibility, availability of the technologies and process options, and administrative feasibility of implementing each alternative. Alternatives that are not technically or administratively feasible—or that will require equipment, specialists, or facilities that are not available within a reasonable period of time—may be eliminated from further consideration.

The comparison of technical and administrative feasibility considered whether (1) the alternatives have a high, moderate, or limited capability of achieving the RAOs and (2) the level of effort required to administratively employ these technology types and process option(s) at the AOC. This comparison was based on past experience and engineering judgment.

Cost This criterion evaluates the financial requirements associated with each of the remedial action alternatives. Consistent with *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (USEPA 1988a), this evaluation employs relative capital and operations and maintenance (O&M) costs for comparison, including factors influencing cost sensitivity. In addition, potential liability associated with untreated contaminated media and treatment residuals is also considered. The cost comparison presented herein identifies costs using relative terms of low, moderate, and high to compare the level of expenditure required to implement and operate the alternative. These relative costs are based on experience and engineering judgment. Detailed cost comparisons are developed in Section 8 for those remedial alternatives determined to be the most effective in achieving the RAOs and implementable at the AOC.

A synopsis of the screening is provided for each remedial alternative. This section reviews the alternatives with respect to effectiveness, implementability, and cost and the decision as to whether the alternative was retained for detailed evaluation or eliminated from further consideration. Alternatives with the most favorable overall effectiveness, implementability, and cost were retained for further evaluation in Section 8.

7.2.1 Alternative 1: No Action

The No Action alternative does not include monitoring or any remedial action components to minimize potential risks to receptors. The No Action alternative was retained for detailed analysis to provide a baseline for comparison with other alternatives consistent with the requirements of *National Oil and Hazardous Substances Pollution Contingency Plan* (USEPA 1991).

Effectiveness Implementation of this alternative will not achieve the RAOs for groundwater or surface water at AOC FS-1. Therefore, the long-term effectiveness and permanence of this alternative in meeting the RAOs is limited. The short-term effectiveness associated with this alternative is considered high because there will be no increase in the potential risk to receptors from the implementation of this alternative at the AOC.

Implementability This alternative could be easily implemented at AOC FS-1.

Cost There is no cost associated with this alternative.

The No Action alternative was retained for detailed evaluation to provide a baseline for comparison with other alternatives consistent with the requirements of CERCLA (USEPA 1988a).

7.2.2 Alternative 2: Limited Action

This alternative involves long-term monitoring and/or site inspection of the AOC, the implementation of institutional controls to reduce the potential for exposure to contaminated groundwater and surface water, and 5-year reviews of Alternative 2. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs. This alternative does not include remedial actions to minimize potential risks to receptors at the AOC. Modeling conducted for the Limited Action alternative estimates that RAOs will be achieved in 11 years.

The estimated time for restoration of the aquifer is 11 years. A combination of model runs 16 and 17 are the basis for the estimate of 11 years. Runs 16 and 17 rely on natural flow to the bogs. The modeling report is included as Appendix B.

This alternative includes the following activities.

- Groundwater monitoring in the source area and downgradient plume.
- Surface water monitoring in the Quashnet River bogs area.
- Institutional controls to prevent consumption of groundwater and restrict contact with surface water.
- 5-year reviews.
- Natural attenuation has occurred and will continue to occur for fuel constituents in the source area.

The continuing monitoring program will involve groundwater and surface water sampling for EDB by USEPA Method 504, VOCs by USEPA Method 524, and metals by USEPA Method methodologies. Site inspections and collection and analysis of samples will be performed quarterly for the first 2 years and annually thereafter for 23 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event. The application of administrative access restrictions at the AOC will require a total of approximately 1 year to develop and implement for this AOC.

Effectiveness Implementation of this alternative will achieve the RAOs by preventing exposure to contaminants. Alternative 2 does not provide treatment to reduce the toxicity, mobility, and/or volume of contaminants at the AOC. However, because the plume is finite, the toxicity, mobility, and/or volume of contamination will not exist after completion of Alternative 2. The long-term effectiveness and permanence of this alternative was considered to be high. However, the alternative does not meet the USEPA preference for treatment. The short-term effectiveness associated with this alternative was considered to be low because there will be no decrease in the potential risk to receptors during the implementation of this alternative at the AOC.

Implementation Long-term monitoring, deed restrictions, and warning signs are commonly employed process options. These actions are readily available and commonly employed process options. However, the effectiveness of such institutional controls is dependent on local government for implementation and enforcement. Implementation of this alternative will require approval from the appropriate state and local authorities. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs.

Cost The total capital cost of the Limited Action alternative is associated with placing deed and zoning restrictions on the AOC. Therefore, the initial capital costs will be relatively low, but this alternative does contain a protracted expenditure associated with long-term monitoring. Maintenance and sampling of the wells will be an appreciable cost. Overall, cost will be low. This alternative will meet the RAOs at the completion the alternative; it is implementable and

effective long term. However, the Institutional Action alternative was eliminated from further consideration for AOC FS-1 because of concern related to the short-term effectiveness and because Alternative 2 does not reduce toxicity, mobility, and/or volume or satisfy the preference for treatment.

7.2.3 Alternative 2B: Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge

Alternative 2B includes groundwater extraction and treatment of groundwater at the leading edge of the plume, institutional controls to prevent usage of the aquifer during cleanup, and surface water restrictions to prevent contact with surface water until surface water contains acceptable levels of EDB. During operation, this alternative minimizes risk to human receptors potentially exposed to surface water and groundwater. This alternative also includes long-term monitoring and/or site inspection in the source area and groundwater and surface water downgradient of the source area. The alternative meets RAOs, specifically protection of human health.

The estimated time for restoration of the aquifer is 11 years. The estimate is derived from model run 17 contained in Appendix B. The model predicts that the leading edge extraction system effectively removes EDB from the aquifer and prevents discharge of EDB to the Quashnet River bogs. Modeling also indicates that the proposed public supply well P-11 would not be impacted by this alternative, nor would P-11 pump water containing EDB from the FS-1 plume. Surface water will be restored within 1 year of April 1999. The restoration of surface water within the 1-year time frame is the result of the extraction and treatment of groundwater that is presently being remediated by the Quashnet River Bogs Pilot test.

This alternative includes the following activities:

- leading edge extraction, treatment, and reinjection/discharge;
- groundwater monitoring in the source area and downgradient plume;
- surface water monitoring in the Quashnet River area bogs;
- institutional controls;
- operation and maintenance; and
- 5-year reviews.

The extraction system will be composed of one high-volume extraction well (EW-5), which would pump at approximately 200 gpm, and 135 shallow well points that would be pumped at approximately 400 gpm. All water from the extraction wells would be piped to a treatment facility, located adjacent to bogs, where the 600 gpm pumped from the wells would be treated by pumping the extracted water through GAC. After treatment, the water would be reinjected to the aquifer and discharged to surface water. Two hundred gallons per minute would be reinjected to the aquifer through approximately 19 wells. The remaining 400 gpm would be discharged to the surface water in the Quashnet River bogs. Additionally, water discharged to the bogs may be run through a bubbler before discharge to oxygenate the water. A berm also would be constructed to separate areas of potential contaminated groundwater upwelling from areas in which there is no potential contaminated groundwater upwelling.

The monitoring program will involve groundwater and surface water sampling for EDB by USEPA Method 504, VOCs by USEPA Method 524, and metals by USEPA method methodologies. Site inspections and collection and analysis of samples will be performed quarterly for the first 2 years and annually thereafter for 9 years. The sampling, analysis, data validation, and preparation of a monitoring report would require approximately 12 weeks per sampling event. The application of administrative access restrictions at the AOC would require a total of approximately 1 year to develop and implement for this AOC. Treatment system operation would continue for 11 years.

Details of the Quashnet River Bogs Pilot Test effort are described in *Quashnet River Bogs Pilot Test* (Jacobs 1999). Applicable sections of that report are contained in Appendix E. The pilot test is presently functioning and comprises the extraction, treatment, and reinjection/discharge portions of Alternative 2B.

Effectiveness Implementation of this alternative will achieve the RAOs at the completion of remedial action. The RAO of restoring surface water to cleanup levels will occur shortly after remediation is begun. The RAO of restoring groundwater to cleanup levels will not be achieved until the remedial action is complete. Alternative 2B does provide treatment to reduce the toxicity, mobility, and/or volume of contaminants at the AOC. The long-term effectiveness and permanence of this alternative was considered to be high. The short-term effectiveness associated with this alternative was considered to be low because there will be no reduction in the toxicity, mobility, and/or of groundwater upgradient of the extraction system. Workers may be exposed to contamination during construction and implementation of Alternative 2B. Such risks can be minimized with adequate work practices. Risks to the community will not increase as a result of construction and implementation. There is potential that the ecology could be negatively impacted by Alternative 2B during construction and implementation. Such impacts can be mitigated with engineering controls and monitoring of the environment as are included in this alternative.

Implementation Long-term monitoring, zoning restrictions, and warning signs are commonly employed process options. These actions are readily available and commonly employed process options. However, the effectiveness of such institutional controls is dependent on local government for implementation and enforcement. Construction of the described remedial system is implementable and has been completed. The materials and services required by this alternative are readily available. Implementation of this alternative would require approval from the appropriate state and local authorities. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs.

Cost The capital cost of Alternative 2B is moderate. Monitoring and O&M costs are also moderate. Overall cost is moderate.

This alternative will meet the RAOs at the completion of the alternative and will protect receptors during operation of the alternative. Alternative 2B, Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge, was retained for further consideration for AOC FS-1.

7.2.4 Alternative 3: Axial Well Extraction, Treatment, and Reinjection/Discharge

Alternative 3 includes groundwater extraction from wells located at the leading edge of the plume, treatment of the extracted groundwater, institutional controls to prevent usage of the aquifer during cleanup, and surface water restrictions to prevent contact with surface water until surface water contains acceptable levels of EDB. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs. During operation, this alternative minimizes risk to human receptors potentially exposed to surface water and groundwater. This alternative also includes long-term monitoring and/or site inspection in the source area and in groundwater and surface water downgradient of the source area. The alternative meets RAOs, specifically protection of human health.

Preliminary modeling of a groundwater extraction system suggests that such a system is feasible. Several modeling runs were performed for various numbers of wells and extraction rates. Runs used to evaluate the axial well alternative include runs 2, 5, 7, and 19. The chosen well configuration was optimized to remediate contamination without undue stress on the Quashnet River and associated bogs. At a pumping rate of approximately 600 gpm, site cleanup with the chosen well configuration is estimated to require approximately 7 years. The reduced time to groundwater cleanup (over extraction at the toe of the plume) is due to the shorter distance that contaminated water must travel to an axial well before being extracted by a well. Surface water would be restored to cleanup levels within 1 month of startup. The rapid restoration of surface water is because contaminated groundwater would be extracted from the aquifer and would not discharge to the bogs. An additional modeling run (run 19) was performed to evaluate the possibility of reinjecting water on the flanks of the plume. Results of that run indicate that reinjection negates the southernmost wells, and the recirculation of reinjected water between the reinjection and extraction wells lowers the capture efficiency of the extraction system. Consequently, reinjection at the bogs and discharge to surface water appears to be a better solution. Impacts on the Quashnet River appear to be manageable based on drawdown contours. Modeling indicates that the proposed public supply well P-11 would not be impacted by this alternative, nor would P-11 pump water contaiing EDB from the FS-1 plume. Figures from the solutions are contained in Appendix B.

This alternative includes the following remedial activities to clean up groundwater and surface water:

- axial extraction, treatment, and reinjection/discharge of contaminated groundwater;

- groundwater monitoring in the source area and downgradient plume;
- surface water monitoring in the Quashnet River area bogs;
- institutional controls;
- operation and maintenance; and
- 5-year reviews.

Before construction of Alternative 3, additional modeling and design would be performed to optimize the extraction system. Property would be acquired on which the axial wells and utilities would be installed. Construction would include construction of approximately 2 miles of road to provide access to the axial wells as well as the installation of power lines, control wiring, and piping along the road to connect the wells to the treatment facility. Approximately 20 wells (200 feet deep) would be installed. Present modeling indicates the wells would pump at approximately 600 gpm. A treatment facility would be constructed and treatment equipment installed. For cost purposes, it is assumed that the treatment would be located adjacent to the Quashnet River bog. Nineteen reinjection wells capable of reinjecting 200 gpm would be installed in the bogs, and a surface water discharge system capable of discharging 400 gpm to the bogs would be constructed.

Operation of the described system would continue for 7 years or longer, based on achievement of the RAOs. Institutional controls, in the form of zoning restrictions, would be placed to prevent use of groundwater. Those restrictions would continue until RAOs were met. Additionally, surface water and groundwater would be monitored for the life of the treatment system.

Implementation of this alternative at AOC FS-1 will take approximately 24 months to complete. Monitoring site conditions will involve collecting and analyzing groundwater and surface water samples. The monitoring program will involve taking groundwater and surface water samples from the AOC and analyzing for VOCs by USEPA Method 524, EDB by USEPA Method 504, and metals by USEPA Method 200.7/6010/7000. Source area groundwater will be resampled for metals and VOCs. These site inspections, and collection and analysis of groundwater samples, will be performed quarterly for the first 2 years and annually thereafter for 5 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event. The application of administrative access restrictions at this AOC will require a total of approximately 1 year to develop and implement. Treatment system operation will continue for 7 years.

Effectiveness This alternative has the potential to achieve the RAOs established for AOC FS-1 and to minimize the toxicity, mobility, and/or volume of the contaminants through treatment. This alternative will meet the CERCLA preference for treatment of contaminated media and also will prevent ingestion of the contaminated groundwater and contact with contaminated groundwater. The RAO of reducing contamination in surface water may be achieved early in the remedial action, and institutional controls on surface water will be lifted. The long-term effectiveness was considered high based on the reduction in the potential risks and permanence of the solution. The short-term effectiveness associated with this alternative was considered to be high because construction and implementation of this alternative will not increase risks, and upgradient water will be captured. Workers may be exposed to contamination during construction and implementation of Alternative 3. Such risks can be minimized with

adequate work practices. Risks to the community will not increase as a result of construction and implementation. There is the potential that the ecology could be negatively impacted by Alternative 3 during construction and implementation. Such impacts can be mitigated with engineering controls and monitoring of the environment that are part of this alternative.

Implementation This alternative will require the services of a remediation contractor with specialized equipment to construct the remediation system. Such services are readily available. It may be administratively difficult to obtain the necessary property. The design and implementation of these processes will be implemented with difficulty. Activities associated with this alternative are routinely conducted, and the labor and material are readily available.

Other elements of this alternative will include long-term monitoring, zoning restrictions, and warning signs. These actions are readily available and commonly employed process options. However, the effectiveness of such institutional controls are dependent on local government for implementation and enforcement. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs. Implementation of this alternative will require approval from the appropriate state and local authorities.

Cost The total capital cost of this alternative was considered high. This alternative contains a high initial capital cost and protracted expenditures associated with system operation (over a 7-year period).

This alternative was <u>retained</u> for AOC FS-1. The groundwater treatment will reduce contaminant concentrations and will minimize the toxicity, mobility, and/or volume of the contaminants through treatment. The alternative also satisfies regulatory preference for treatment. The long-term effectiveness of this alternative was considered to be high because of the reduction in the risks.

7.2.5 Alternative 3B: Axial and Leading Edge Extraction, Treatment, and Reinjection/Discharge

This alternative involves the installation of extraction wells, reinjection wells, construction of surface water discharge system, construction of a treatment facility, and all components previously listed under the Limited Action alternative. It is a combination of Alternatives 2B and 3. This alternative will reduce risks and minimize the impact of contaminated groundwater. Preliminary modeling of a groundwater extraction system suggests that such a system is feasible. The chosen well configuration was optimized to remediate contamination without undue stress on the Quashnet and associated bogs. Reinjection to the bogs minimizes negative impact to the bogs. Modeling run 19 performed with reinjection along the boundaries of the plume suggests

that reinjection along the edges of the plume may negatively impact the plume and cause unnecessary recirculation. Discussion of the negative impacts of reinjection along the flanks is discussed in Section 5.3.5 of the modeling report contained in Appendix B. Models suggest that reinjection in the vicinity of the bog and surface water discharge are preferable to injection along the edges of the plume. Modeling indicates that the proposed public supply well P-11 would not be impacted by this alternative, nor would P-11 pump water contaiing EDB from the FS-1 plume. Figures from the solutions are contained in Appendix B.

The estimated time for restoration of the aquifer is 7 years. The estimate is derived from model run 18 contained in Appendix B. The model predicts that the leading edge extraction system effectively removes EDB from the aquifer and prevents discharge of EDB to the Quashnet River bogs. Addition of the axial wells removes EDB from the upgradient aquifer, thereby accelerating groundwater cleanup. Surface water will be restored within 1 year of April 1999. The restoration of surface water within the 1-year time frame is the result of the extraction and treatment of groundwater that is presently being remediated by the Quashnet River Bogs Pilot test.

During operation, this alternative minimizes risk to human receptors potentially exposed to surface water and groundwater. This alternative also includes long-term monitoring and/or site inspection in the source area and groundwater and surface water downgradient of the source area. The alternative meets RAOs, specifically protection of human health.

This alternative includes the following remedial activities for the extraction, treatment, reinjection, and natural attenuation of the groundwater contamination:

- axial and leading edge extraction, treatment, and reinjection/discharge;
- groundwater monitoring in the source area and downgradient plume;
- surface water monitoring in the Quashnet River area bogs;
- institutional controls;
- operation and maintenance; and
- 5-year reviews.

Before construction of Alternative 3B, additional modeling and design would be performed to optimize the extraction system. Property would be acquired on which the axial wells and utilities would be installed. Construction would include construction of approximately 2 miles of road to provide access to the axial wells and installation of power lines, control wiring, and piping along the road to connect the wells to the treatment facility.

The extraction system would be composed of a leading edge extraction system, an axial well extraction system, a treatment system, and a reinjection/discharge system. The leading edge extraction system would be composed of one high-volume extraction well (EW-5), which would pump at approximately 200 gpm, and 135 shallow well points that would be pumped at approximately 400 gpm. The axial well extraction system would be composed of 17 wells along the central axis of the plume that would extract water at 400 gpm. All water from the extraction wells would be piped to a treatment facility, located adjacent to bogs, where the 1,000 gpm pumped from the wells would be treated by pumping the extracted water through granulated activated carbon (GAC). After treatment, the water would be reinjected to the aquifer and

discharged to surface water. Two hundred gallons per minute would be reinjected to the aquifer through approximately 19 wells. The remaining 800 gpm would be discharged to the surface water in the Quashnet River bogs. Additionally, water discharged to the bogs may be run through a bubbler before discharge to oxygenate the water. A berm would also be constructed to separate areas of potential contaminated groundwater upwelling from areas in which there is no potential contaminated groundwater upwelling.

Other elements of this alternative will include long-term monitoring, zoning restrictions, and warning signs. These actions are commonly employed process options. However, the effectiveness of such institutional controls is dependent on local government for implementation and enforcement. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs. Implementation of this alternative will require approval from the appropriate state and local authorities.

Implementation of the processes at AOC FS-1 will take approximately 24 months to complete. Monitoring site conditions will involve collecting and analyzing groundwater and surface water samples. The monitoring program will involve taking groundwater samples from the AOC and analyzing for VOCs by USEPA Method 524, EDB by USEPA Method 504, and metals by USEPA Method 200.7/6010/7000. Source area groundwater will be sampled for potential COCs. These site inspections, and collection and analysis of groundwater samples, will be performed quarterly for the first 2 years and annually thereafter for 5 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event. The application of administrative access restrictions at this AOC will require a total of approximately 1 year to develop and implement. Treatment system operation will continue for 7 years.

Effectiveness This alternative has the potential to achieve the RAOs established for AOC FS-1 and to minimize the toxicity, mobility, and/or volume of the contaminants through treatment. The RAO of reduction of COCs in surface water should be achieved early in the remediation action. This alternative will also prevent ingestion of the contaminated groundwater through the use of institutional controls. The long-term effectiveness was considered high based on the reduction in the potential risks and permanence of the solution. This alternative will meet the CERCLA preference for treatment of contaminated media. The short-term effectiveness associated with this alternative was considered to be high because construction and implementation of this alternative will not increase risks and because upgradient water will be captured. Workers may be exposed to contamination during construction and implementation of Alternative 3B. Such risks can be minimized with adequate work practices. Risks to the community will not increase as result of construction and implementation. There is potential that the ecology could be negatively impacted by Alternative 3B during construction and implementation. Such impacts can be mitigated with engineering controls and monitoring of the environment that are part of this alternative.

Implementation This alternative will require the services of a remediation contractor with specialized equipment to construct the remediation system. Such services are readily available. It may be administratively difficult to obtain the necessary property. The design and implementation of these processes will be implemented with difficulty. Activities associated with this alternative are routinely conducted, and the labor and material are readily available.

Other elements of this alternative will include long-term monitoring, zoning restrictions, and warning signs. These actions are commonly employed process options. However, the effectiveness of such institutional controls is dependent on local government for implementation and enforcement. The authority for institutional controls for FS-1 involve on-base and off-base authorities. For source area groundwater, there is no immediate risk. Residents and workers on the base obtain drinking water from the base water supply system. Construction projects on MMR, including water supply wells, require written approval from the Base Civil Engineer. Construction of a new drinking water supply well for MMR would also require DEP permission. For downgradient groundwater and surface water, institutional controls must be enacted by the Town of Mashpee. Mashpee has placed a moratorium on wells impacted by contaminated groundwater and has posted the Quashnet River cranberry bogs. Implementation of this alternative will require approval from the appropriate state and local authorities.

Cost The total capital cost of this alternative was considered high. This alternative contains a high initial capital cost and protracted expenditures associated with long-term system operation (over a 15-year period).

This alternative was <u>retained</u> for AOC FS-1. The groundwater treatment will reduce contaminant concentrations and will minimize the toxicity, mobility, and/or volume of the contaminants through treatment. The alternative also satisfies regulatory preference for treatment. The long-term effectiveness of this alternative was considered to be high because of the reduction in the risks.

7.3 SUMMARY OF REMEDIAL ACTION ALTERNATIVES

Alternatives with the most favorable composite evaluation of all the factors were retained for further evaluation in Section 8.

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8. DETAILED ANALYSIS OF ALTERNATIVES

Five remedial alternatives were developed and tailored to AOC FS-1 in Section 7. These remedial alternatives were screened in that section against three criteria: effectiveness, implementability, and cost. Four of those alternatives were retained for the detailed evaluation performed in this section. The alternatives are further evaluated to aid in selecting the most appropriate remedy for AOC FS-1 and to demonstrate compliance with the following CERCLA remedy statutory findings:

- protection of human health and the environment;
- attainment of ARARs (or provide grounds for invoking a waiver);
- cost-effectiveness;
- use of permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent possible; and
- satisfaction of the preference for treatment that reduces toxicity, mobility, and/or volume of hazardous substances as a principal element.

Under CERCLA, the following nine evaluation criteria were developed to address the five requirements listed above, as well as other technical and policy considerations important in analyzing remedial alternatives.

The first two criteria (overall protection of human health and the environment and compliance with ARARs) are know as threshold criteria that must be satisfied for an alternative to be selected.

- **Overall Protection of Human Health and the Environment** This criterion was used to assess whether the alternative adequately protects human health and the environment and describes how long- and/or short-term risks posed through each pathway are eliminated, reduced, or controlled through treatment, engineering controls, or institutional controls.

- **Compliance with ARARs** This criterion is used to assess how each alternative complies with federal and selected state regulations that have been identified as applicable or relevant and appropriate to the alternative.

The following five criteria are known as primary balancing criteria. If an alternative meets the threshold criteria, the primary balancing criteria are used to evaluate those alternatives that meet the threshold criteria.

- **Long-term Effectiveness and Permanence** This criterion addresses the magnitude of risk that may remain after remedial response objectives have been met by implementation of the alternative. Adequacy and reliability of controls that may be necessary to manage residual risk are also considered under this criterion. Additionally, in this criterion, percent capture and treatment to background if technically and economically feasible, potential impacts to planned P-11 water supply, and risks associated with the uncaptured potion of the plume were evaluated.

- **Reduction of Toxicity, Mobility, and/or Volume Through Treatment** This criterion is used to evaluate whether each alternative satisfies the statutory preference for selecting remedial actions that permanently and significantly reduce toxicity, mobility, and/or volume of hazardous substances through treatment.

- **Short-term Effectiveness** This criterion is used to assess the short-term effects on human health and the environment during construction and implementation of the alternative until remedial response objectives are met. This criterion considers protection of the community and workers, potential environmental impacts and mitigation of these impacts, and the overall time for achieving remedial response objectives.

- **Implementability** This criterion is used to evaluate an alternative based upon the technical and administrative feasibility of its execution. Technical feasibility considers the alternative's ability to be constructed, operated, and adequately monitored; reliability; and ability to accommodate phase implementation or modifications based upon monitoring results. Administrative feasibility considers activities that require coordination with other offices and agencies and addresses the availability of necessary equipment and specialists, services and materials, and prospective technologies.

- **Cost** This criterion is used to compare the cost of implementing each alternative at the AOC. Costs are intended to provide an accuracy range of -30 to +50% of the actual cost (USEPA 1988a). These costs do not represent actual construction cost estimates or real costs at completion. The components included in the cost estimate follow.

  Capital Costs Capital costs consist of direct (construction) and indirect expenses (nonconstruction and overhead) associated with the installation and implementation of the alternative. Direct costs include expenditures for equipment, labor, and materials necessary for installing systems associated with the alternative. Indirect costs include expenditures for engineering, financial, and other services that are not part of the actual installation process.

  Annual O&M Costs O&M costs are expenses that are assumed to be incurred annually following construction. These costs are considered necessary to ensure the continued functioning and effectiveness of the implemented alternative.

  Present Worth Analysis A present worth analysis evaluates expenditures that occur over time by adjusting costs for inflation and discounting all future costs to a common base year. This analysis provides a single value representing the initial investment required at the start of the remedial process that will be sufficient to cover all costs associated with the selected alternative over its projected life span. The present worth analysis assumes a 5% annual inflation over the life of the alternative that is returned to present worth using a 7% discount rate.

The last two criteria are known as modifying criteria and are evaluated upon the receipt of comments during the public comment period of the Proposed Plan.

- **State Acceptance** This criterion requires evaluation of technical and administrative issues and concerns that the state may have regarding alternatives. This criterion will be addressed

in the Record of Decision (ROD) after comments regarding the FS and Proposed Plan are received; therefore, this criterion is not discussed during this detailed analysis of alternatives.

- **Community Acceptance** This criterion requires evaluation of issues and concerns the public may have regarding alternatives. This criterion will be addressed in the ROD after comments regarding the FS and Proposed Plan are received; therefore, this criterion is not discussed during this detailed analysis of alternatives.

For groundwater and surface water at AOC FS-1 contaminated with EDB, toluene, lead, and thallium, four remedial alternatives were retained for detailed analysis to achieve the following RAOs:

- Prevent or reduce exposure to groundwater contaminant(s) of concern exceeding cleanup standards in groundwater.
- Restore the aquifer to beneficial uses within a reasonable time frame.
- Prevent or reduce worker, recreational youth, and adult wader contact with Quashnet River water containing unacceptable concentrations of EDB and ingestion of fish exposed to Quashnet River water containing unacceptable concentrations of EDB.

These alternatives include No Action; Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge; Axial Well Extraction, Treatment, and Reinjection/Discharge; and Axial and Leading Edge Extraction, Treatment, and Reinjection/Discharge. The detailed analysis for each alternative is presented in the following subsections. Refer to Section 7 for a detailed description of each alternative.

8.1 ALTERNATIVE 1: NO ACTION

The No Action alternative consists of maintaining AOC FS-1 in the current condition. No remedial actions will be undertaken to reduce risk, and no monitoring and/or site inspection programs will be initiated to track the migration of contaminants. This alternative serves as a baseline alternative against which other remedial technologies or alternatives are compared, as required by CERCLA (USEPA 1988a).

Overall Protection of Human Health and the Environment This alternative requires no remedial action; therefore, the long-term risks to human health and the environment will be consistent with the risks identified in the baseline risk assessment discussed in Section 3.

The PRA did identify human health risk above regulatory risk management guidelines. Risk to potential human receptors was above USEPA guidelines for EDB, toluene, and lead in groundwater and EDB in surface water. The No Action alternative will not reduce this risk and, therefore, was not considered to protect receptors.

Compliance with ARARs The primary chemical-, location-, and action-specific ARARs for the AOC are summarized below.

Chemical Specific

- **Groundwater** Chemical-specific ARARs would not be met for 11 years based on modeling.

Location Specific

- No location-specific ARARS requiring compliance were identified for this alternative.

Action Specific

- No action-specific ARARS requiring compliance were identified for this alternative.

Long-term Effectiveness and Permanence The No Action alternative will not achieve the RAOs for AOC FS-1. It will not reduce human exposure to contaminants within the groundwater plume emanating from AOC FS-1. In addition, the No Action alternative will not provide for long-term effectiveness and permanence.

Reduction of Toxicity, Mobility, and/or Volume Through Treatment The No Action alternative will not use treatment, removal, or off-site disposal activities. Consequently, this alternative will not reduce the toxicity, mobility, and/or volume of contamination at this AOC. However, the volume of groundwater contaminants will be reduced over time through attenuation. Overall, the No Action alternative will not satisfy the regulatory preference for treatment as a possible component of a remedial action.

Short-term Effectiveness Implementation of this alternative will not involve intrusive activities. Therefore, there will be no additional risk to human health or the environment contributing additional risk above levels currently associated with AOC FS-1.

Implementability

- **Technical Feasibility** No remedial activities will be implemented with this alternative; therefore, there are no technical difficulties associated with the No Action alternative.

- **Administrative Feasibility** No activities will be implemented with this alternative; therefore, there are no administrative difficulties associated with the No Action alternative.

The No Action alternative will not limit or interfere with additional, potential future remedies.

Cost There are no capital costs and/or O&M costs associated with implementing this alternative.

8.2 ALTERNATIVE 2B: LIMITED ACTION WITH LEADING EDGE EXTRACTION, TREATMENT, AND REINJECTION/DISCHARGE

As a result of the screening conducted and discussed in Section 7, this alternative was retained for the detailed analysis. The Institutional Action alternative meets RAOs at the

completion of the alternative and was retained. Additionally, Alternative 2B meets those RAOs related to surface water shortly after initiation of the action. A 12-month pilot study for the leading edge extraction is currently underway; operations began April 1999 and will be completed by April 2000. The expected reduction of EDB in surface water is expected to occur within 1 year of startup of April 1999.

Alternative 2B includes the following components:

- leading edge extraction, treatment, and reinjection/discharge;
- groundwater monitoring in the source area and downgradient plume;
- surface water monitoring in the source area and downgradient plume;
- institutional controls;
- operation and maintenance; and
- 5-year reviews.

Institutional controls will be employed that include placing of zoning restriction. Identified restrictions include restrictions preventing use of impacted groundwater for 11 years, bans on fishing in the Quashnet River bogs, and posting of the bogs to prevent exposure to surface water. Depending on the effectiveness of the Quashnet River Bogs Pilot Test, it is anticipated that administrative controls could be lifted on surface water within 1 year.

The monitoring program will involve groundwater and surface water sampling for EDB by USEPA Method 504, VOCs by USEPA Method 524, and metals by USEPA method methodologies. Site inspections and collection and analysis of groundwater samples will be performed quarterly for the first 2 years and annually thereafter for 13 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event.

The leading edge groundwater extraction aspect of Alternative 2B includes:

- installation of one deep extraction well pumping at approximately 200 gpm;
- installation of 135 shallow well points pumping a total of 400 gpm;
- construction of a treatment facility using activated carbon adsorption capable of treating 600 gpm;
- installation of 19 reinjection wells capable of injecting 200 gpm;
- construction of a surface water discharge system capable of discharging 400 gpm to the bog area;
- construction of berms to separate areas of upwelling contaminated groundwater from areas in the bog at which contaminated groundwater does not upwell;
- operation and maintenance of the system; and
- performance of an ecological sampling program to ensure that groundwater extraction, treatment, and reinjection/discharge does not impact sensitive aquatic habitat.

Overall Protection of Human Health and the Environment The actions performed within this alternative are protective of human health and the environment. Providing restrictions on the use of groundwater from the AOC FS-1 plume will be protective by not allowing consumption of that groundwater. Restrictions on surface water and fish will be protective by preventing contact

with groundwater and consumption of fish. Within a short period, the Leading Edge Extraction, Treatment, and Reinjection/Discharge alternative will restore background conditions to surface water in the bogs.

Compliance with ARARS The primary chemical-, location-, and action-specific ARARS for the AOC are summarized below.

Chemical Specific

- **Groundwater** It is expected that through capture and treatment at the leading edge of the plume, the groundwater at AOC FS-1 will meet MCLs, non-zero maximum contaminant level goals (MCLGs) and Massachusetts maximum contaminant levels (MMCLs) within 11 years.

- **Surface Water** The Institutional Action with Bog Separation/Protection Action alternative complies with federal AWQC and water quality standards.

Location Specific

- **Wetlands and Floodplains** Remedial actions will be performed in such a manner that wetland areas and floodplains will not be adversely impacted. Additionally, fill material will not be inadvertently discharged to wetlands. Engineering controls will be used to prevent such discharges.

- **Fish and Wildlife** Before modification of the bogs, the U.S. Fish and Wildlife Service will be consulted.

- **Endangered Wildlife** Endangered or threatened species will be identified during design. Activities will be conducted in a fashion that will not adversely impact sensitive species.

Action Specific

- **Groundwater** Multiple ARARS related to groundwater have been identified. Identified ARARS include the Federal Safe Drinking Water Act (SDWA), Massachusetts Groundwater Discharge Permits, Underground Water Source Protection, and Drinking Water Standards. In all instances, remedial actions will comply with those ARARS.

- **Surface water** Discharge of treated water into surface water will be in accordance with the National Pollutant Discharge Elimination System (NPDES).

- **Air** Multiple ARARS associated with air have been identified. Identified air-related ARARS include RCRA Air Emission Standards and Control of Emissions of Volatile Organic Compounds and Massachusetts Air Pollution Control Requirements. Construction and on-site treatment activities will be performed to comply with identified ARARS.

- **Solid Waste** Investigation-derived waste will comply with applicable standards and requirements.

- **Hazardous Waste Generators** All hazardous waste generated will comply with state and federal RCRA requirements.

- **Food Tolerance** Massachusetts Department of Public Health (DPH) food tolerance levels for EDB in food products will be complied with. Cranberry testing would be undertaken as an additional measure of the performance of the alternative in attaining the surface water RAO.

Long-term Effectiveness and Permanence The Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge alternative will achieve the RAOs for AOC FS-1. Modeling for this alternative estimates that the MMCL of 0.02 μg/L EDB in groundwater will be achieved within 11 years. At 11 years, the average concentration of EDB is less than 0.02 μg/L. Of the estimated total of 11 kg of EDB in the aquifer, modeling indicates that 68% will be extracted by the remediation system, 18% will escape the extraction system and discharge beyond the model boundaries, and 14% will remain dispersed through the aquifer. It is assumed that that portion of EDB that escapes extraction and is not retained in the aquifer discharges to surface water. If the EDB is not extracted, nor does it escape the boundaries of the plume, it is assumed to be immobile. The portion of EDB that is not extracted and does not escape the boundaries of the model is assumed to be either trapped in silts, in blind pores that are not connected to other pores that will allow transport, or is dissipated through the aquifer. It is anticipated that the surface water RAOs will be achieved within 1 year of system startup. The pilot system startup for the bog separation is scheduled for April 1999. It will reduce human exposure to contaminants within the groundwater plume emanating from AOC FS-1 and surface water in the Quashnet River bogs. Modeling also indicates that the proposed public supply well P-11 would not be impacted by this alternative, nor would P-11 pump water containing EDB from the FS-1 plume. The Leading Edge Extraction, Treatment, and Reinjection/Discharge alternative is operational as the Quashnet River Bogs Pilot Test. The Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge alternative will provide for long-term effectiveness and permanence.

Reduction of Toxicity, Mobility, and/or Volume Through Treatment Alternative 2B will use treatment activities. Consequently, this alternative will reduce the toxicity, mobility, and/or volume of contamination at this AOC. Overall, the Limited Action with Leading Edge Extraction, Treatment, and Reinjection/Discharge alternative will satisfy the regulatory preference for treatment as a component of a remedial action.

Short-term Effectiveness Implementation of this alternative will involve intrusive actions. Additional risk to human health or the environment during implementation will be mitigated though personal protection and engineering controls contributing additional risk above levels currently associated with AOC FS-1. Short-term risks to the community will be minimal because there is no residential housing in close proximity to the areas where construction will occur. Any contact between residents and site contaminants will be insignificant.

Implementability

- **Technical Feasibility** There are technical difficulties associated with Alternative 2B. Potential difficulties include construction of stable berms over unstable organic materials,

fouling of small-diameter wells if high entrance velocities are used, construction of stable piping networks between wells in the bogs, metals precipitation in GAC filter canisters, channelization of the GAC filter canisters, and other problems. However, those problems can be overcome with good engineering and construction practices.

- **Administrative Feasibility** There may be administrative difficulties associated with the Institutional Action with Bog Separation/Protection alternative. The plume is outside the boundaries of the base and will require coordination with municipal authorities to ensure adequate restrictions are placed on the use of groundwater and surface water. Permitting associated with the construction and operation of the treatment system will require ongoing coordination with public agencies.

Cost

- **Capital Cost** The principal capital cost components for this alternative will be associated with the construction of the Leading Edge Extraction, Treatment, and Reinjection/Discharge system. Estimated capital costs are $3,952,000.

- **O&M Cost** The O&M costs incurred by implementing this alternative will be for O&M of the remediation system, performing groundwater monitoring, and site inspections. Total O&M costs for the life of the project are estimated at $5,543,000.

- **Present Worth** The total present worth for this alternative was calculated using an inflation of 5% annually, then calculating present worth based on a 7% annual discount rate. All calculations assume that O&M activities will extend for 11 years. This results in a present worth cost of $9,423,000. A summary of costs and assumptions for this alternative is presented in Appendix C.

8.3 ALTERNATIVE 3: AXIAL WELL EXTRACTION, TREATMENT, AND REINJECTION/DISCHARGE

As a result of the screening conducted and discussed in Section 7, the Axial Well Extraction, Treatment, and Reinjection/Discharge alternative was retained for the detailed analysis. The alternative meets RAOs at the completion of the alternative. Additionally, Alternative 3 would meet RAOs related to surface water within 1 year of system startup.

Alternative 3 has the following components:

- axial extraction, treatment, and reinjection/discharge;
- groundwater monitoring in the source area and downgradient plume;
- surface water monitoring in the Quashnet River area bogs;
- institutional controls;
- operation and maintenance; and
- 5-year reviews.

A long-term groundwater monitoring program will be implemented that involves the sampling and evaluation of groundwater quality at the AOC over a 7-year period. Monitoring wells adequate for such monitoring exist at the AOC. Surface water will also be monitored. Monitoring site conditions will involve collecting and analyzing groundwater and surface water samples. The monitoring program will involve taking groundwater and surface water samples from the AOC and analyzing for VOCs by USEPA Method 624, EDB by USEPA Method 504, and metals by USEPA Method 200.7/6010/7000. These site inspections, and the collection and analysis of groundwater samples, will be performed quarterly for the first 2 years and annually thereafter for 5 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event.

Institutional controls will be employed that include placing of zoning restrictions on the AOC to limit site activities. Identified restrictions include restrictions preventing use of impacted groundwater for 7 years, bans on fishing in the Quashnet River bogs, and posting of the bogs to prevent exposure to surface water. Depending on the effectiveness Alternative 3, it is anticipated that administrative controls could be lifted on surface water within 1 year. The application of administrative access restrictions at this AOC will require a total of approximately 1 year to develop and implement for this AOC.

The monitoring program will involve groundwater and surface water sampling for EDB by USEPA Method 504, VOCs by USEPA Method 524, and metals by USEPA method methodologies. Site inspections and collection and analysis of groundwater samples will be performed quarterly for the first 2 years and annually thereafter for 5 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event. The application of administrative access restrictions at this AOC will require a total of approximately 1 year to develop and implement for this AOC.

The active treatment for Alternative 3 includes the following.

- During the design of this alternative, additional modeling will be necessary to optimize the extraction system.
- Sampling and analysis will be performed to verify the boundaries of contamination that exceeds the MCLs. Additional bounding wells will be installed.
- Property necessary to the extraction wells will be acquired. Acquisition may be through lease or purchase.
- The site will be prepared by constructing road(s) along the proposed path of extraction wells. For cost purposes, it is assumed that 3 miles of gravel road will be created.
- Power and well controls wiring will be installed along the roadway(s).
- Installation of approximately 20 deep extraction wells pumping at approximately 600 gpm.
- Construction of a treatment facility using activated carbon adsorption capable of treating 600 gpm.
- Installation of 19 reinjection wells capable of injecting 200 gpm.
- Construction of a surface water discharge system capable of discharging 400 gpm to the bog area.
- Operation and monitoring of the system will continue for 7 years.
- Performance of an ecological sampling program to ensure that groundwater extraction, treatment, and reinjection/discharge does not impact sensitive aquatic habitat.

Implementation of the active remediation processes at the AOC will begin within 15 months of signature of the final ROD.

Overall Protection of Human Health and the Environment Groundwater contaminants will be removed from the aquifer. During removal of the contamination, institutional controls will prevent the use of contaminated groundwater. Achievement of groundwater RAOs should occur within 7 years. Surface water RAOs should be achieved within 1 year of treatment system startup. Therefore, this alternative will be protective of human health and the environment.

Compliance with ARARS The primary chemical-, location-, and action-specific ARARS for the AOC are summarized below.

Chemical Specific

- **Groundwater** It is expected that through the axial extraction and treatment of the plume, groundwater at AOC FS-1 will meet MCLs, non-zero MCLGs, and MMCLs within 7 years.

Location Specific

- **Wetland/Floodplains** Infiltration galleries constructed in the vicinity of the bogs will be constructed in a fashion that minimizes impact to the bogs. No fill or dredge will be discharged to the bogs.
- **Other Natural Resources** If infiltration galleries are installed, the galleries will be designed to ensure that the waters of the Quashnet River are not negatively impacted.
- **Wildlife** Remedial activities will be structured such that endangered or threatened species are not adversely impacted.

Action Specific

- **Groundwater** Any injection of groundwater will meet SDWA standards and applicable state standards for injection before injection of that water.
- **Surface Water** Discharge of treated water into surface water will be in accordance with NPDES.
- **Waste Materials** All identified regulations, advisories, and guidance relevant to the handling of wastes generated during construction and operation of the remediation system will be met.
- **Air** Multiple ARARS associated with air have been identified. Identified air-related ARARS include RCRA Air Emission Standards and Control of Emissions of Volatile Organic Compounds and Massachusetts Air Pollution Control Requirements. Construction and on-site treatment activities will be performed to comply with identified ARARS.

- **Food Tolerance** Massachusetts DPH food tolerance levels for EDB in food products will be complied with. Cranberry testing would be undertaken as an additional measure of the performance of the alternative in attaining the surface water RAO.

Long-term Effectiveness and Permanence The long-term effectiveness and permanence of this alternative is considered high based on the reduction of risk to receptors and the removal of contamination from the aquifer and surface water. Modeling for this alternative estimates that the MMCL of 0.02 μg/L EDB in groundwater will be achieved within 7 years. At 7 years, the average concentration of EDB is less than 0.02 μg/L. Of the estimated total of 11 kg of EDB in the aquifer, modeling indicates that 83% will be extracted by the remediation system, 11% will escape the extraction system and discharge beyond the model boundaries, and 6% will remain dispersed through the aquifer. It is assumed that that portion of EDB that escapes extraction and is not retained in the aquifer discharges to surface water. If the EDB is not extracted, nor does it escape the boundaries of the plume, it is assumed to be immobile. The portion of EDB that is not extracted and does not escape the boundaries of the model is assumed to be either trapped in silts, in blind pores that are not connected to other pores that will allow transport, or is dissipated through the aquifer. It is anticipated that the surface water RAOs will be achieved within 1 year of system startup. Modeling also indicates that the proposed public supply well P-11 would not be impacted by this alternative, nor would P-11 pump water containing EDB from the FS-1 plume. If Alternative 3 is chosen, system startup should occur by the summer of 2000. The groundwater and surface water monitoring and site inspection programs will document the continued effectiveness of this alternative.

Reduction of Toxicity, Mobility, and/or Volume Through Treatment This alternative will reduce the toxicity, mobility, and/or volume of groundwater contamination through treatment The reduction in toxicity and volume will be attained by removing the contaminants from groundwater, thereby reducing discharge of contaminants to surface water. The reduction in mobility will be achieved by drawing the contamination into extraction wells. This alternative satisfies CERCLA's statutory preference for treatment as a principal component of a remedial action.

Short-term Effectiveness While implementing this alternative, there may be elevated risks to workers implementing this alternative and to the environment. Potential elevated risk may result from exposure to contaminated groundwater during the implementation of this alternative. To reduce this risk, workers performing the installation activities may be required to use personal protective equipment and/or minimize their exposure to contaminated groundwater. Short-term risks to the community will be minimal because, except for one home at the head of the plume, there is no residential housing in close proximity to the areas where construction will occur. Any contact between residents and site contaminants will be insignificant. Short-term impacts to the environment will be minimized, to the extent possible, through the use of common erosion controls such as hay bales and silt fencing.

Implementability

- **Technical Feasibility** Alternative 3 will be moderately difficult to implement. Sophisticated modeling and engineering will be required to design an effective system that does not negatively impact the environment. The implementation of this alternative will

require the use of equipment and services commercially available from local vendors. Components and items associated with this alternative will be readily available. Accessibility to the site by the necessary vehicles will be difficult. Road construction is necessary.

- **Administrative Feasibility** Implementation and supervision of the design, construction, and O&M of the alternative will require close coordination with local, state, and federal agencies. The implementation of institutional controls and access restrictions associated with this alternative will require administrative and regulatory support from local, state, and federal agencies. There may be administrative difficulties associated with aspects of this alternative. The plume is outside the boundaries of the base and will require coordination with municipal authorities to ensure adequate restrictions are placed on the use of groundwater.

Cost

- **Capital Cost** The principal capital cost components for this alternative will be associated with the construction of the extraction, treatment, and reinjection/discharge systems. Estimated capital costs are $4,626,000.

- **O&M Cost** The O&M costs incurred by implementing this alternative will be for O&M of the remediation system, performing groundwater monitoring, and site inspections. Total O&M costs for the life of the project are estimated at $4,041,000.

- **Present Worth** The total present worth for this alternative was calculated using an inflation of 5% annually, then calculating resent worth based on a 7% annual discount rate. All calculations assume that O&M activities will extend for a period of 7 years. This results in a present worth cost of $8,699,000. A summary of costs and assumptions for this alternative is presented in Appendix C.

8.4 ALTERNATIVE 3B: AXIAL AND LEADING EDGE EXTRACTION, TREATMENT, AND REINJECTION/DISCHARGE

As a result of the screening conducted and discussed in Section 7, Alternative 3B, the Axial and Leading Edge Extraction, Treatment, and Reinjection/Discharge alternative, was retained for detailed analysis. The alternative meets RAOs at the completion of the alternative and was retained. Additionally, Alternative 3B meets RAOs related to surface water shortly after initiation of the action. The leading edge aspect of Alternative 3B has been installed as the Quashnet River Bogs Pilot Test and is operational. Expected reduction of COCs in surface water are expected by April 1999.

Alternative 3B has the following components:

- axial and leading edge extraction, treatment, and reinjection/discharge;
- groundwater monitoring in the source area and downgradient plume;
- surface water monitoring in the Quashnet River area bogs;
- institutional controls;

- operation and maintenance; and
- 5-year reviews.

A long-term groundwater monitoring program will be implemented that involves the sampling and evaluation of groundwater quality at the AOC for EDB over a 7-year period. Monitoring wells adequate for such monitoring exist at the AOC. Surface water will also be monitored. Additionally, wells in the source area will be resampled for metals and VOCs to verify the presence of VOCs and metals above background and MCLs. The monitoring program will involve groundwater and surface water sampling for EDB by USEPA Method 504, VOCs by USEPA Method 524, and metals by USEPA method methodologies. Site inspections and collection and analysis of groundwater samples will be performed quarterly for the first 2 years and annually thereafter for 13 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event.

Institutional controls will be employed that include placing of zoning restrictions on the AOC to limit site activities. Identified restrictions include restrictions preventing use of impacted groundwater for 7 years, bans on fishing in the Quashnet River bogs, and posting of the bogs to prevent exposure to surface water. Depending on the effectiveness of the leading edge extraction aspect of Alternative 3B, it is anticipated that administrative controls could be lifted on surface water within 1 year. The leading edge extraction system is operational as the Quashnet River Bogs Pilot Test, and it is expected that surface contamination will be eliminated by April 1999. The application of administrative access restrictions at this AOC will require a total of approximately 1 year to develop and implement.

The Axial Well Extraction/Treatment/Recharge with Bog Separation/Protection Actions includes the following.

- Additional modeling to optimize the extraction system.
- Sampling and analysis to verify the boundaries of contamination that exceeds the MCLs. Additional bounding wells will be installed.
- Acquisition of property necessary to the extraction wells will be acquired. Acquisition may be through lease or purchase.
- Site preparation by constructing road(s) along the proposed path of extraction wells. For cost purposes, it is assumed that 3 miles of gravel road will be created.
- Installation of power and well controls wiring along the roadway(s).
- Installation of 17 deep axial extraction wells pumping at approximately 400 gpm.
- Installation of one deep extraction well pumping at approximately 200 gpm.
- Installation of 135 shallow well points pumping a total of 400 gpm.
- installation of 19 reinjection wells capable of injecting 200 gpm.
- Construction of a surface water discharge system capable of discharging 800 gpm to the bog area.
- Construction of berms to separate areas of upwelling contaminated groundwater from areas in the bog at which contaminated groundwater does not upwell.
- Construction of additional treatment facility capacity using activated carbon adsorption to create a treatment facility capable of treating 1,000 gpm.
- Operation and maintenance of the system for 7 years.

- Performance of an ecological sampling program to ensure that groundwater extraction, treatment and reinjection/discharge does not impact sensitive aquatic habitat.

Construction activities associated with the Quashnet River Bogs Pilot Test are complete. Implementation of the axial well extraction system and enlargement of the treatment facility and discharge systems will begin within 15 months of signature of the final ROD.

Monitoring site conditions will involve collecting and analyzing groundwater and surface water samples. The monitoring program will involve taking groundwater and surface water samples from the AOC and analyzing for VOCs by USEPA Method 624, EDB by USEPA Method 504, and metals by USEPA Method 200.7/6010/7000. These site inspections, and the collection and analysis of groundwater samples, will be performed quarterly for the first 2 years and annually thereafter for 5 years. The sampling, analysis, data validation, and preparation of a monitoring report will require approximately 12 weeks per sampling event.

Overall Protection of Human Health and the Environment Groundwater contaminants will be removed from the aquifer. During removal of the contamination, administrative controls will prevent the use of contaminated groundwater. Reduction of COCs in surface water to RAOs should occur within 1 year of treatment system startup. The leading edge extraction aspect of Alternative 3B has been completed as the Bog Pilot Test. It is expected that surface water will meet RAOs by April 2000. This alternative will be protective of human health and the environment.

Compliance with ARARS The primary chemical-, location-, and action-specific ARARS for the AOC are summarized below.

Chemical Specific

- **Groundwater** It is expected that through capture and treatment at the leading edge of the plume, the groundwater at AOC FS-1 will meet MCLs, non-zero MCLGs, and MMCLs within 7 years.

- **Surface Water** Alternative 3B complies with federal AWQC and water quality standards.

Location Specific

- **Wetlands and Floodplains** Remedial actions will be performed in such a manner that wetland areas and floodplains will not be adversely impacted. Additionally, fill material will not be inadvertently discharged to wetlands. Engineering controls will be used to prevent such discharges.

- **Fish and Wildlife** Before modification of the bogs, the U.S. Fish and Wildlife Service will be consulted.

- **Wildlife** Remedial activities will be structured such that endangered or threatened species are not adversely impacted.

- **Other Natural Resources** If infiltration galleries are installed, the galleries will be designed to ensure that the waters of the Quashnet River are not negatively impacted.

<u>Action Specific</u>

- **Groundwater** Any injection of groundwater will meet SDWA standards and applicable state standards for injection before injection of that water.

- **Surface water** Discharge of treated water into surface water will be in accordance with NPDES.

- **Air** Multiple ARARS associated with air have been identified. Identified air-related ARARS include RCRA Air Emission Standards and Control of Emissions of Volatile Organic Compounds and Massachusetts Air Pollution Control Requirements. Construction and on-site treatment activities will be performed to comply with identified ARARS.

- **Waste Materials** All identified regulations, advisories, and guidance relevant to the handling of wastes generated during construction and operation of the remediation system will be met.

- **Food Tolerance** Massachusetts DPH food tolerance levels for EDB in food products will be complied with. Cranberry testing would be undertaken as an additional measure of the performance of the alternative in attaining the surface water RAO.

Long-term Effectiveness and Permanence The long-term effectiveness and permanence of this alternative is considered high based on the reduction of risk to receptors and the removal of contamination from the aquifer and surface water. Modeling for this alternative estimates that the MMCL of 0.02 μg/L EDB in groundwater will be achieved within 7 years. At 7 years, the average concentration of EDB is less than 0.02 μg/L. Of the estimated total of 11 kg of EDB in the aquifer, modeling indicates that 83% will be extracted by the remediation system, 11% will escape the extraction system and discharge beyond the model boundaries, and 6% will remain dispersed through the aquifer. It is assumed that that portion of EDB that escapes extraction and is not retained in the aquifer discharges to surface water. If the EDB is not extracted, nor does it escape the boundaries of the plume, it is assumed to be immobile. The portion of EDB that is not extracted and does not escape the boundaries of the model is assumed to be either trapped in silts, in blind pores that are not connected to other pores that will allow transport, or is dissipated through the aquifer. Modeling also indicates that the proposed public supply well P-11 would not be impacted by this alternative, nor would P-11 pump water containing EDB from the FS-1 plume. It is anticipated that the surface water RAOs will be achieved within 1 year of system startup. If Alternative 3B is chosen, complete system startup should occur by the summer of 2000. The leading edge extraction, treatment, and reinjection/discharge aspect of Alternative 3B is operational as the Quashnet River Bogs Pilot Test. Consequently, achievement of surface water RAOs is anticipated by April 2000. The groundwater and surface water monitoring and site inspection programs will document the continued effectiveness of this alternative.

Reduction of Toxicity, Mobility, and/or Volume Through Treatment This alternative will reduce the toxicity, mobility, and/or volume of groundwater contamination through

treatment. Surface water will be replaced with clean, treated water. The reduction in toxicity and volume will be attained by removing the contaminants from groundwater. The reduction in mobility will be achieved by drawing the contamination into extraction wells. This alternative satisfies CERCLA's statutory preference for treatment as a principal component of a remedial action.

Short-term Effectiveness While implementing this alternative, there may be risks to workers implementing this alternative and to the environment. Potential risk may result from exposure to contaminated groundwater during the implementation of this alternative. To reduce this risk, workers performing the installation activities may be required to use personal protective equipment and/or minimize their exposure to contaminated groundwater. Short-term risks to the community will be minimal because, with the exception of one dwelling at the head of the plume, there is no residential housing in close proximity to where the construction will occur. Any contact between residents and site contaminants will be insignificant. Short-term impacts to the environment will be minimized, to the extent possible, through the use of common erosion controls such as hay bales and silt fencing.

Implementability

- **Technical Feasibility** Alternative 3B will be moderately difficult to implement. Sophisticated modeling and engineering will be required to design an effective system that does not negatively impact the environment. The implementation of this alternative will require the use of equipment and services commercially available from local vendors. Components and items associated with this alternative will be readily available. Accessibility to the site by the necessary vehicles will be difficult. Road construction is necessary.

- **Administrative Feasibility** Implementation and supervision of the design, construction, and O&M of the alternative will require close coordination with local, state, and federal agencies. The implementation of institutional controls and access restrictions associated with this alternative will require administrative and regulatory support from local, state, and federal agencies. There may be administrative difficulties associated with aspects of this alternative. The plume is outside the boundaries of the base and will require coordination with municipal authorities to ensure adequate restrictions are placed on the use of groundwater.

Cost

- **Capital Cost** The principal capital cost components for this alternative will be associated with the construction of the extraction, treatment, and reinjection systems. Estimated capital costs are $6,385,00.

- **O&M Cost** The O&M costs incurred by implementing this alternative will be for O&M of the remediation system, performing groundwater monitoring, and site inspections. Total O&M costs for the life of the project are estimated at $4,149,000.

- **Present Worth** The total present worth for this alternative was calculated using an inflation of 5% annually, then calculating present worth based on a 7% annual discount rate. All

calculations assume that O&M activities will extend for a period of 7 years. This results in a present worth cost of $10,561,000. A summary of costs and assumptions for this alternative is presented in Appendix C.

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9. COMPARATIVE ANALYSIS OF ALTERNATIVES

The comparative analysis evaluates the remedial alternatives considered for AOC FS-1 with respect to the nine criteria established by USEPA (1988b) and defined in Section 8. The purpose of the comparative analysis is to identify the advantages and disadvantages of implementing alternatives in relation to one another. This comparison will be used in the eventual selection of a remedial alternative for contaminated groundwater at the site.

9.1 APPROACH TO THE COMPARATIVE ANALYSIS

Specific CERCLA requirements are considered when comparing alternatives for selection of a preferred site remedy. To the extent practicable, the selected alternative should:

- protect human health and the environment;
- attain ARARS (or provide grounds for invoking a waiver);
- be cost-effective;
- use permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent possible; and
- satisfy the preference for treatment that reduces toxicity, mobility, and/or volume of hazardous substances as a principal element.

Comparison of alternatives and final remedy selection are based on an evaluation of the major trade-offs among the alternatives in terms of the nine evaluation criteria. USEPA categorized the evaluation criteria into three levels: threshold, balancing, and modifying criteria.

9.1.1 Threshold Criteria

The threshold criteria are:

- protection of human health and the environment and
- compliance with ARARS.

These are considered threshold criteria because they establish the minimum requirements that a remedial alternative must meet. Therefore, these criteria establish the minimum threshold that must be reached. To be eligible for selection as the preferred alternative at the AOC, the alternative must meet each of these criteria.

9.1.2 Primary Balancing Criteria

The primary balancing criteria are:

- long-term effectiveness and permanence;
- reduction of toxicity, mobility, and/or volume through treatment;
- short-term effectiveness;
- implementability; and

- cost.

These five criteria are considered the balancing criteria. A remedial action is not required to meet all five of these criteria; however, the remedial action should strive to meet as many of these criteria as possible. The effectiveness of a remedial action in achieving these criteria may sway favor toward one alternative or another. These criteria provide a preliminary evaluation of the extent to which the alternative employs permanent solutions and treatment in a cost-effective manner to achieve the site RAO.

9.1.3 Modifying Criteria

The modifying criteria are:

- support agency acceptance and
- community acceptance.

These are the final criteria in determining the preferred alternative for the AOC. The results of support agency or community comments may serve to modify the remedial alternative. As stated in Section 8, these criteria will be addressed in the ROD after consideration of comments regarding the FS and the Proposed Plan.

9.2 COMPARATIVE ANALYSIS OF ALTERNATIVES

Table 9.1 presents a comparative analysis of alternatives for AOC FS-1.

9.2.1 Overall Protection of Human Health and the Environment

All the alternatives except Alternative 1 (No Action) provide adequate protection of human health and the environment. Although the reduction in risk was not calculated, groundwater is restored to drinking water standards (MCLs). At the time that MCLs are achieved, a risk assessment will be performed to determine risks posed by MCLs. If residual risk remains after achieving MCLs, additional or other remedial actions may be taken. Surface water is protected by the alternatives through the extraction of groundwater. Alternatives 2B, 3, and 3B prevent further migration of contaminated groundwater by extracting and treating the plume to health-based ARARs. Human health is protected during implementation of Alternatives 2B, 3, and 3B by restricting the use of groundwater, limiting exposure to surface water, and restricting consumption of fish.

Alternative 3B is considered the most protective of human health because is incorporates the currently operating Bog Separation Project. Alternative 3 provides less overall protection because that system is not currently operating and most probably would not be operational until late 2000. Alternative 2B is less effective because it does not remove as much mass of EDB from the aquifer.

Alternatives 3 and 3B are considered most protective of human health and the environment because (based on modeling) these alternatives meet RAOs within 7 years. Alternative 2B achieves RAOs within 11 years.

9.2.2 Compliance with ARARs

The evaluation of the ability of the alternatives to comply with ARARs included a review of chemical-specific, action-specific, and location-specific ARARs that was presented earlier in this report. All the alternatives will meet all the their respective ARARs except the No Action alternative.

9.2.3 Long-term Effectiveness and Permanence

Alternatives 2B, 3 and 3B provide good long-term effectiveness and permanence because all three alternatives use treatment technologies to reduce hazards posed by contaminants in groundwater and surface water. Alternative 1 does not provide long-term effectiveness and permanence.

Alternative 3B relies on the extraction of groundwater along the axis of the plume and at the toe of the plume. This configuration results in shorter flowpaths to the extraction system than does Alternative 2B. Modeling indicates that the MCL of 0.02 μg/L will be achieved in 7 years. Note that the effectiveness of the system is dependent on the startup date. The model assumes that the extraction system is currently operating. If system startup is delayed, the amount of EDB captured by the system will decrease. A portion of Alternative 3B, the extraction at the toe of the plume, is currently operational as the Bog Separation Pilot Study. It is extracting EDB. The model indicates that the Alternative 3B extraction and treatment system will extract 83% of EDB contained in the aquifer. Eleven percent of the EDB will escape the extraction system according to model calculations. Review of the groundwater flow patterns indicates that the EDB escapes to the Quashnet River. Six percent of the EDB will be retained in the aquifer and be trapped in either silts or blind pores. The model also indicates that minimal additional reduction of EDB concentrations is achieved through additional operation of the extraction system after 7 years. The risks associated with the EDB that escapes the extraction system or is retained in the aquifer is minimal. If the EDB discharges to the Quashnet River, the EDB that discharges will no longer be a risk in groundwater. A ratio analysis of risk indicates that the surface water RME cancer risk from the EDB that escapes to the Quashnet River will be 6.6×10^{-6} and the CTE will be 7×10^{-7}. The portion of EDB that remains in the aquifer is immobile and does not cause a risk to human health or the environment. Modeling also indicates that public supply well P-11 will not impact the extraction of EDB, nor will P-11 pull in EDB. The primary reasons for this is that contaminated groundwater is not within the zone of contribution of P-11.

Alternative 3 relies on the extraction of groundwater along the axis of the plume. This configuration results in shorter flowpaths to the extraction system than does Alternative 2B. Modeling indicates that the MCL of 0.02 μg/L will be achieved in 7 years. Note that the effectiveness of the system is dependent on the startup date. The model assumes that the extraction system is currently operating. If system startup is delayed, the amount of EDB captured by the system will decrease. No portion of Alternative 3 is presently extracting

contaminated groundwater. The model indicates that the Alternative 3 extraction and treatment system will extract 83% of the EDB contained in the aquifer. Eleven percent of the EDB will escape the extraction system according to model calculations. Review of the groundwater flow patterns indicates that the EDB escapes to the Quashnet River. Six percent of the EDB will be retained in the aquifer and be trapped in either silts or blind pores. The model also indicates that minimal additional reduction of EDB concentrations is achieved through additional operation of the extraction system after 7 years. The risks associated with the EDB that escapes the extraction system or is retained in the aquifer are minimal. If the EDB discharges to the Quashnet River, the EDB that discharges will no longer be a risk in groundwater. A ratio analysis of risk indicates that the surface water RME cancer risk from the EDB that escapes to the Quashnet River will be 6.6×10^{-6} and the CTE will be 7×10^{-7}. The portion of EDB that remains in the aquifer is immobile and does not cause a risk to human health or the environment. Modeling also indicates that public supply well P-11 will not impact the extraction of EDB, nor will P-11 pull in EDB. The primary reason for this is that contaminated groundwater is not within the zone of contribution of P-11.

Alternative 2B relies on the extraction of groundwater at the toe of the plume and is consequently dependent on the natural flow of groundwater to the extraction system. Modeling indicates that the MCL of 0.02 μg/L will be achieved in 11 years. Also note that the effectiveness of the system is dependent on the startup date. The model assumes that the extraction system is currently operating. If system startup is delayed, the amount of EDB captured by the system will decrease. The pilot system that is the basis for Alternative 2B is currently operating and extracting EDB. The model indicates that the extraction and treatment system will extract 68% of the EDB contained in the aquifer. Eighteen percent of the EDB will escape the extraction system. Review of the groundwater flow patterns indicates that the EDB escapes to the Quashnet River. Twelve percent of the EDB will be retained in the aquifer and be trapped in either silts or blind pores. Based on modeling results, minimal additional reduction of EDB concentrations will be achieved through additional operation of the extraction system after 11 years. The risks associated with the EDB that escapes the extraction system or is retained in the aquifer is minimal. If the EDB discharges to the Quashnet River, the EDB that discharges will no longer be a risk in groundwater. A ratio analysis of risk indicates that the surface water RME cancer risk from the EDB that escapes to the Quashnet River will be 1.1×10^{-5} and the CTE will be 7×10^{-7}. The portion of EDB that remains in the aquifer is immobile and does not cause a risk to human health or the environment. Modeling also indicates that public supply well P-11 will not impact the extraction of EDB, nor will P-11 pull in EDB. The primary reasons is that contaminated groundwater is not within the zone of contribution of P-11.

Alternatives 2B, 3, and 3B would reduce contaminant mobility, toxicity, and/or volume. Alternative 3B maximizes reduction of contaminant mobility, toxicity, and/or volume. Alternative 3 does not reduce contaminant mobility, toxicity, and/or volume as well as does Alternative 3B because the bog separation aspect of Alternative 3B is already extracting contaminants and Alternative 3 will not extract contaminants until some future date. Consequently, some contamination captured by Alternative 3B will escape Alternative 3. Alternative 2B reduces contaminant toxicity, mobility, and/or volume less than Alternative 3 or Alternative 3B because that system removes less contamination from the aquifer based on modeling results. Alternative 1 would not reduce toxicity, mobility, and/or volume and

availability through treatment. Alternatives 2B, 3, and 3B satisfy the preference for treatment. Alternative 1 does not.

Alternatives 2B, 3, and 3B would be short-term effective. All three alternatives would protect human health and the environment during implementation of the alternative. Workers constructing or operating the remedial system could be exposed to the contamination during construction and implementation of the remedial actions. Also, there is the potential for contaminants to be released into the environment during construction. However, exposure of workers to contaminants and releases of contaminants to the environment could be controlled, thereby reducing such problems. Alternative 1 is not protective of human health or the environment.

Alternative 3B is the most difficult to implement. Alternative 3 would be less difficult than 3B, and 2B would be less difficult than 3 or 3B. This variation in difficulty is directly related to the amount of construction required for each option. However, all such activities are common groundwater cleanup components and do not present any unusual implementation issues. Alternative 1 is easily implemented.

Alternative 3B is the most expensive alternative ($10,561,000 present worth cost for 7 years), followed by Alternative 3 ($8,699,000 present worth cost for 7 years), Alternative 2B ($9,423,000 present worth cost for 11 years), and Alternative 1 at $0.

Table 9.1 presents the results of the comparative analysis for the AOC.

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FIGURES

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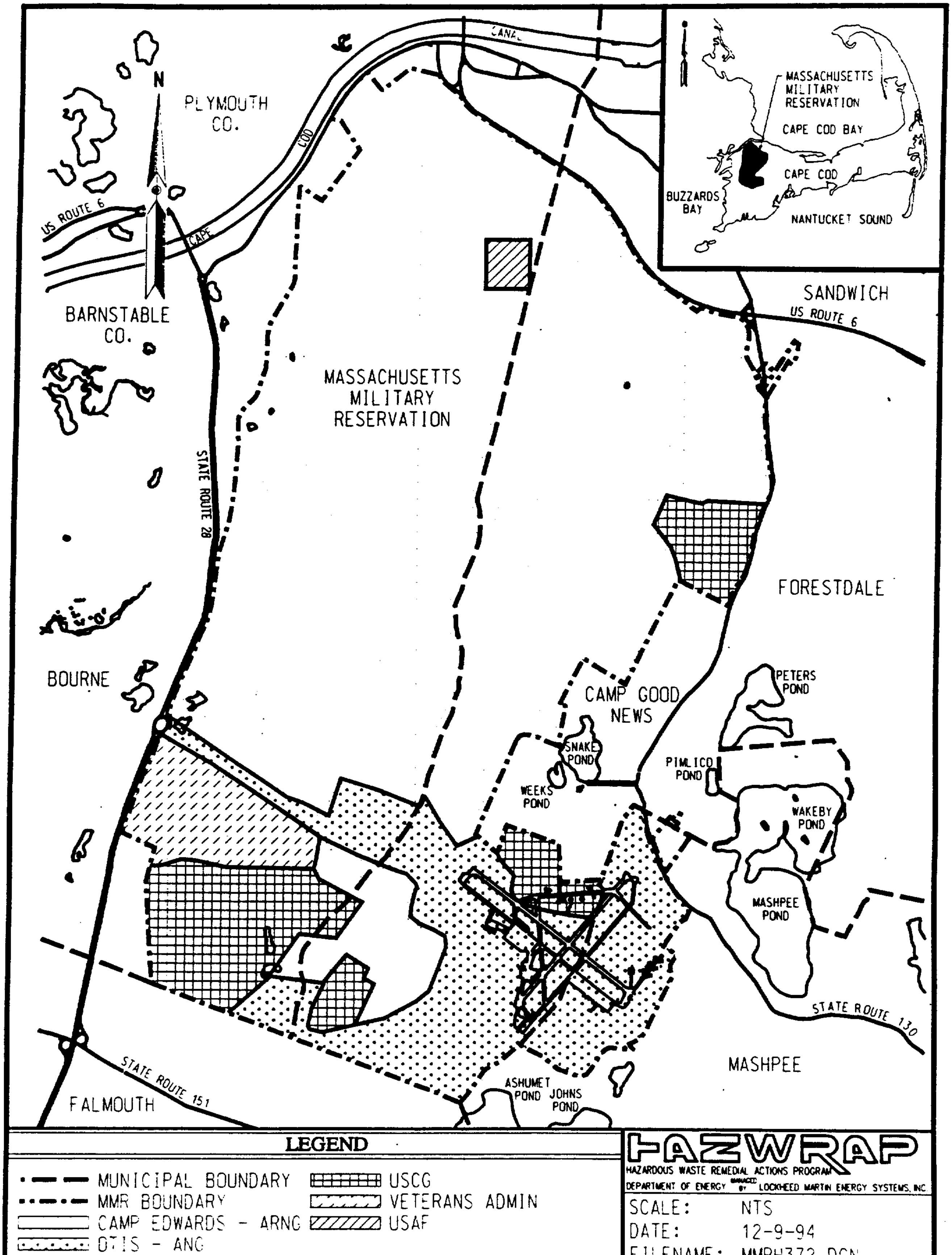
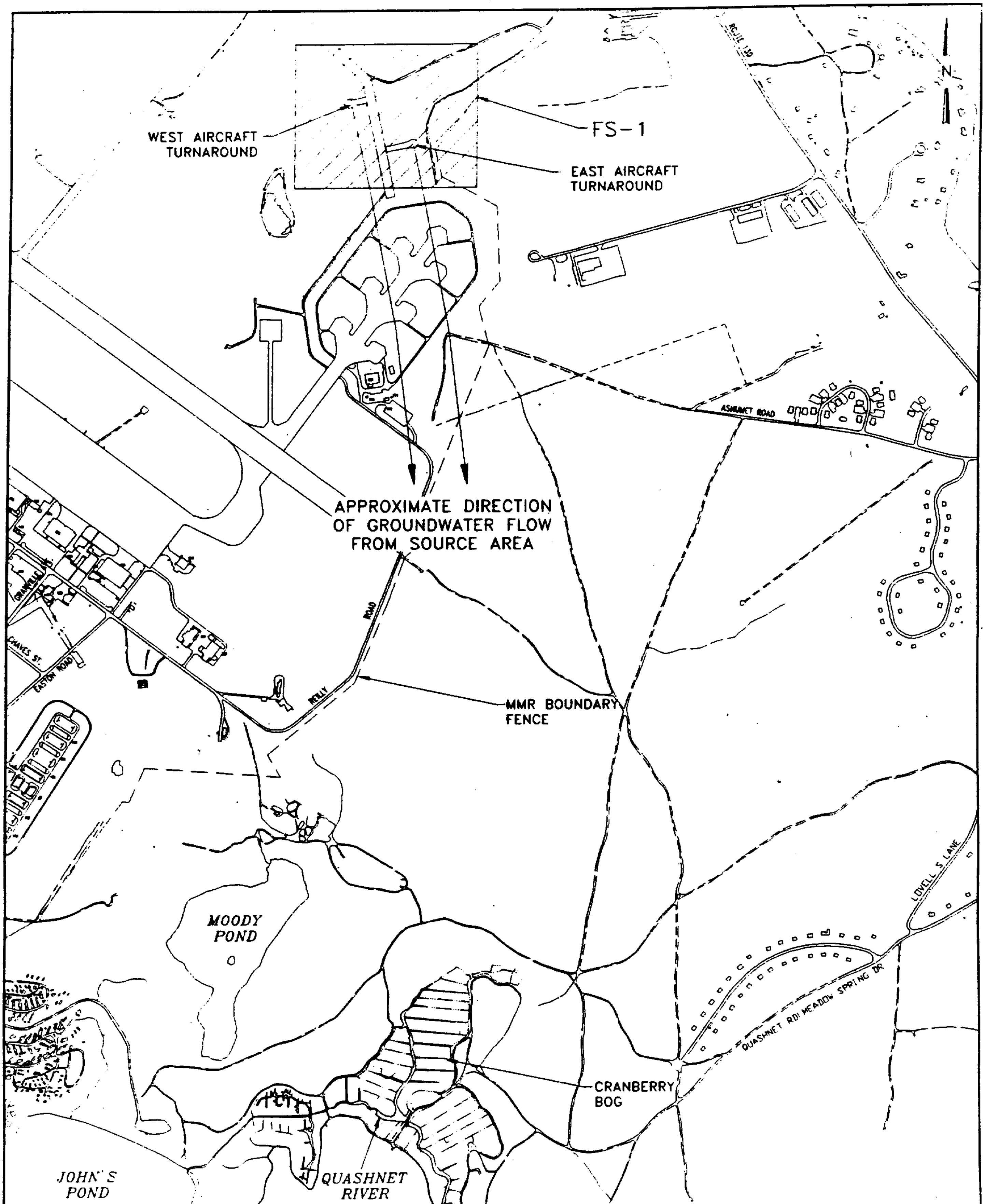


Figure 2-1. Regional location map of the MMR area.



HAZWRAP
HAZARDOUS WASTE REMEDIAL ACTIONS PROGRAM
DEPARTMENT OF ENERGY MANAGED BY LOCKHEED MARTIN ENERGY SYSTEMS, INC

SCALE IN FEET
800 400 0 400 800

FIGURE 2-2
AOC FS-1 Area Site Map
AOC FS-1 Feasibility Study
Massachusetts Military Reservation

SCALE	AS NOTED	DWN BY	KVP
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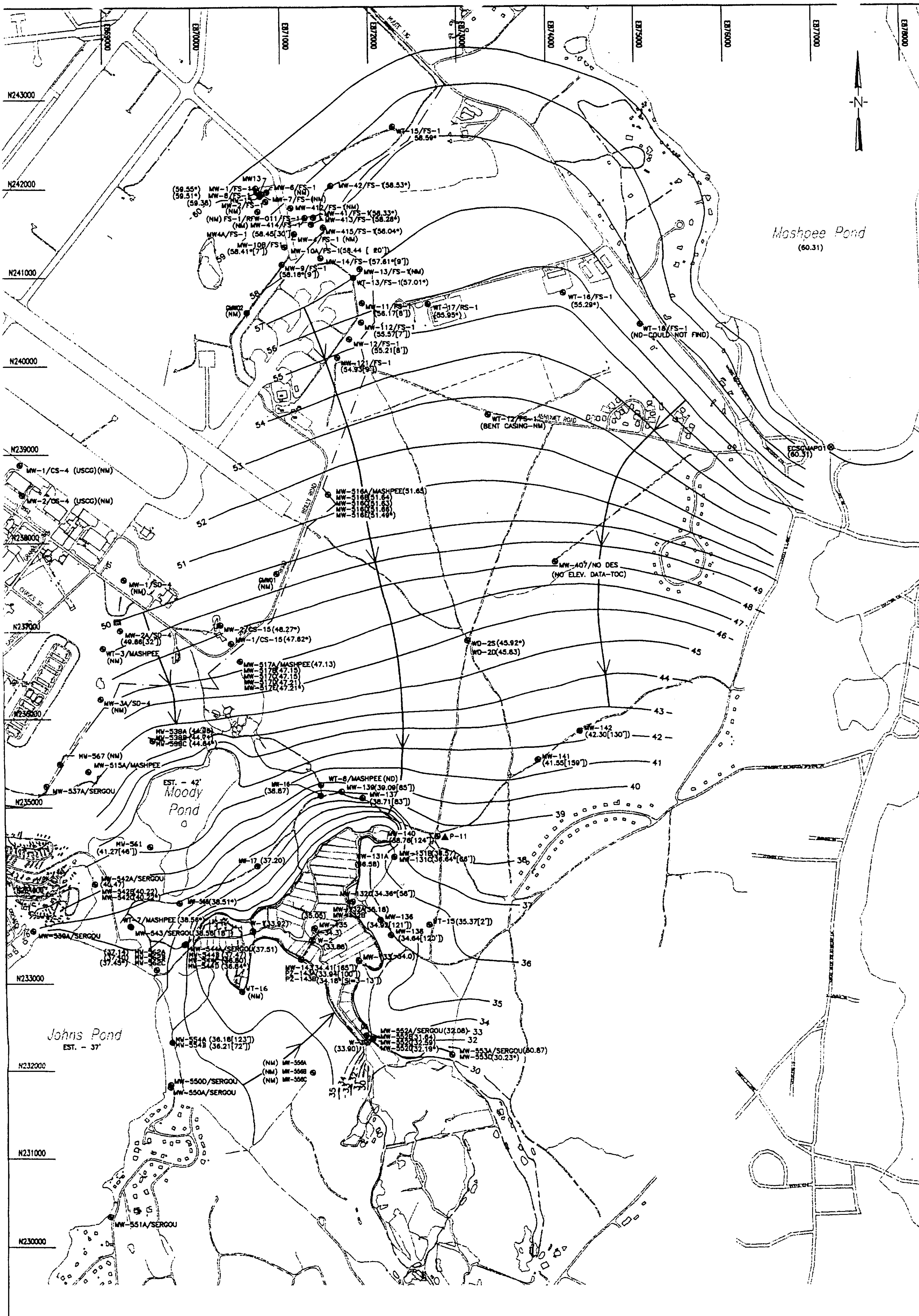


LEGEND

- ▲ EXISTING PUMP TEST WELL
- ● WELL LOCATION
- — GROUNDWATER CONTOURS
- ⊗ STAFF GAGE
- * INDICATES VALUES USED IN CONTOURING
- → GROUNDWATER FLOW

● MW-141 — WELL NUMBER

(41.55[159']) — GROUNDWATER ELEVATION; DISTANCE FROM WATER LEVEL TO TOP OF SCREEN

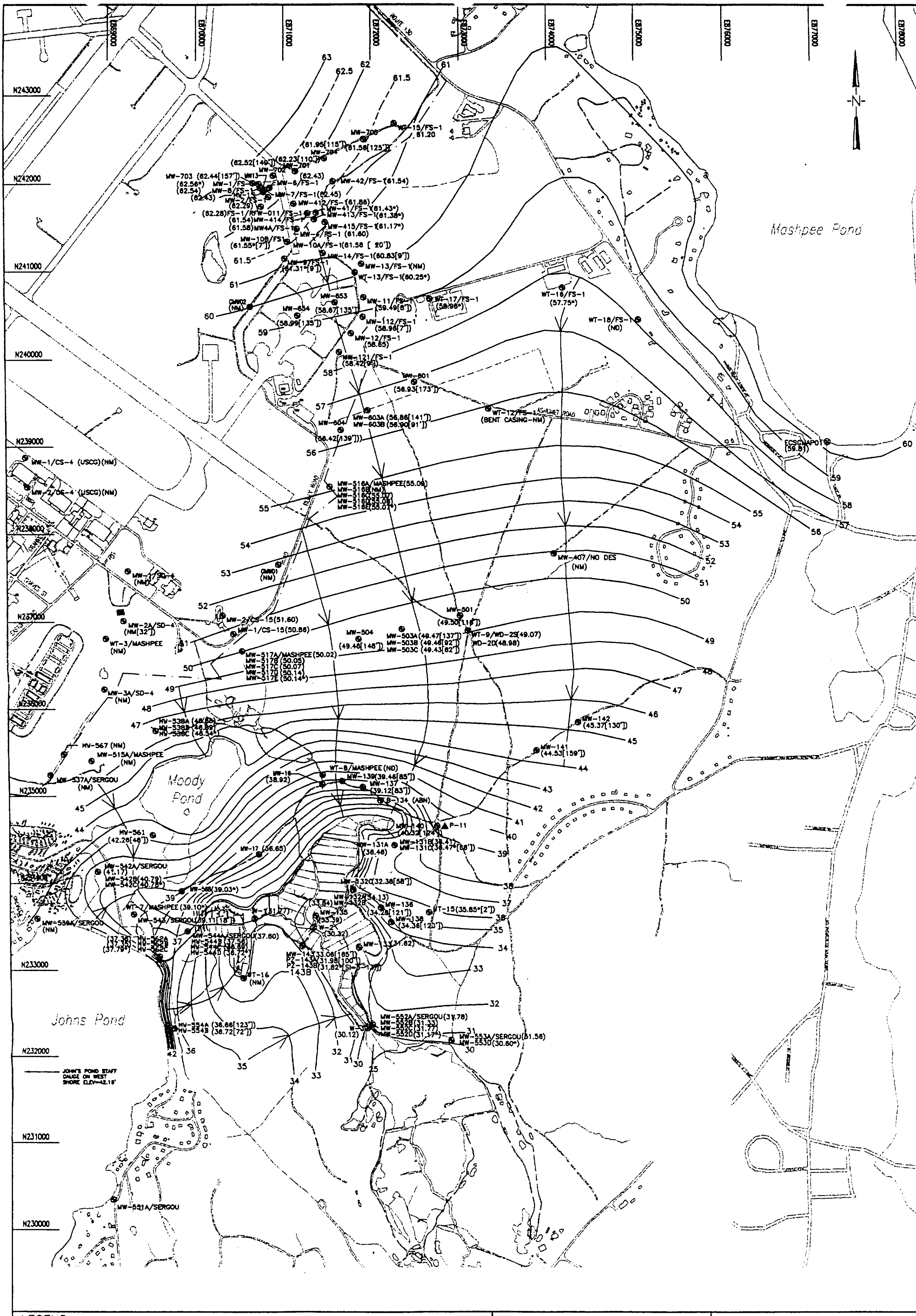
COMMODORE
ADVANCED SCIENCES, INC.

SCALE IN FEET

1000 500 0 500 1000

FIGURE 2-3
WATER TABLE CONTOUR MAP
JANUARY 28 AND 29, 1998
AOC FS-1 Feasibility Study
Massachusetts Military Reservation

SCALE: 1"=1000'
DWN BY: KVP



LEGEND

- ▲ EXISTING PUMP TEST WELL
- ⊙ WELL LOCATION
- —— GROUNDWATER CONTOURS
- ⊗ STAFF GAGE
- • INDICATES VALUES USED IN CONTOURING
- → GROUNDWATER FLOW

WELL NUMBER — ⊙ MW-141

(41.55[159'])

GROUNDWATER ELEVATION — DISTANCE FROM WATER LEVEL TO TOP OF SCREEN

COMMODORE
ADVANCED SCIENCES, INC.

SCALE IN FEET

1000 500 0 500 1000

FIGURE 2-4
WATER TABLE CONTOUR MAP
APRIL 16 AND 17, 1998

AOC FS-1 Feasibility Study
Massachusetts Military Reservation

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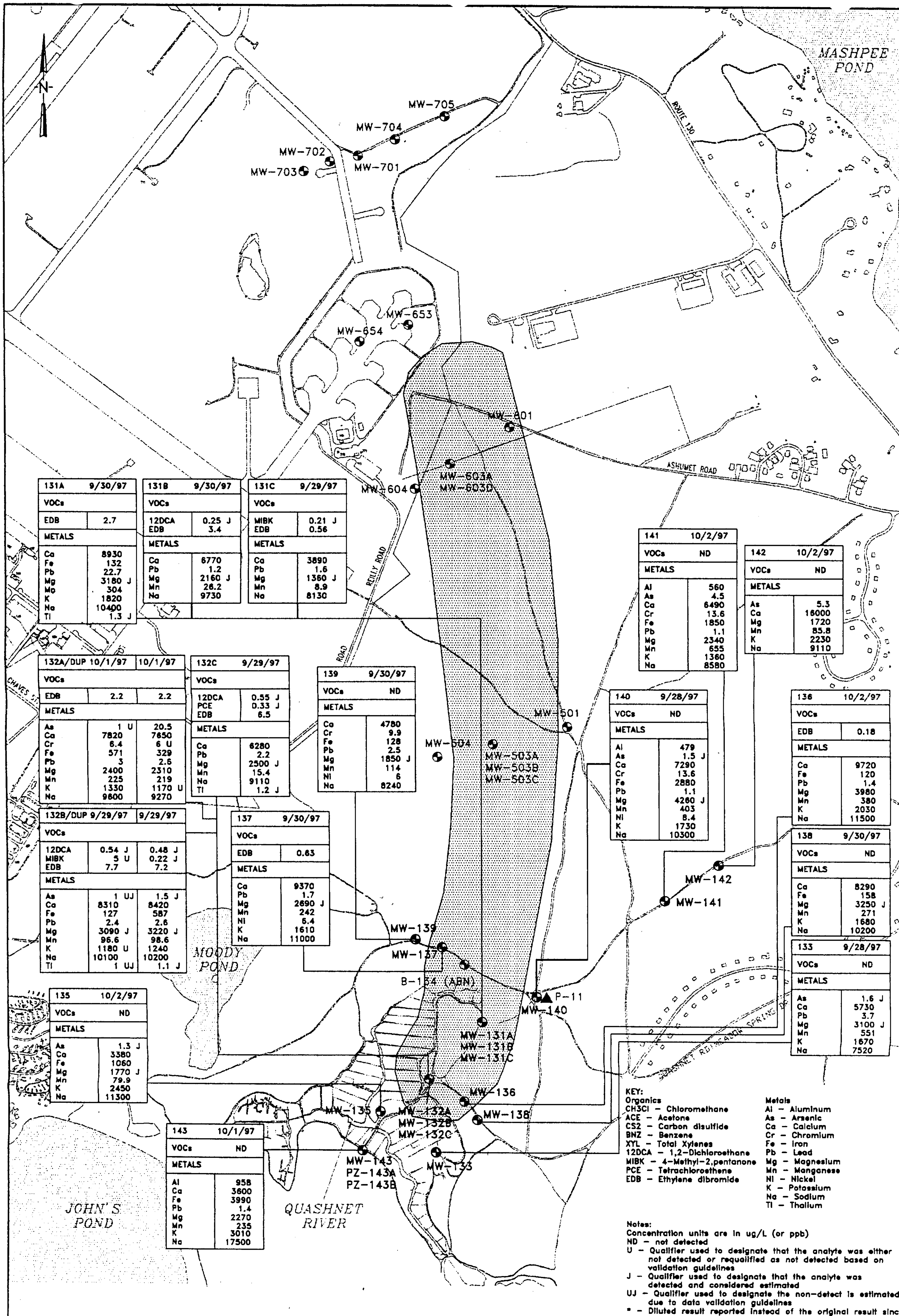

LEGEND

- 1997/1998 MONITORING WELL
- EXISTING PUMP TEST WELL
- APPROXIMATE EDB PLUME

COMMODORE ADVANCED SCIENCES, INC.

SCALE IN FEET

800 400 0 400 800

FIGURE 2-5
EXTENT OF EDB PLUME

AOC FS-1 Feasibility Study
Massachusetts Military Reservation

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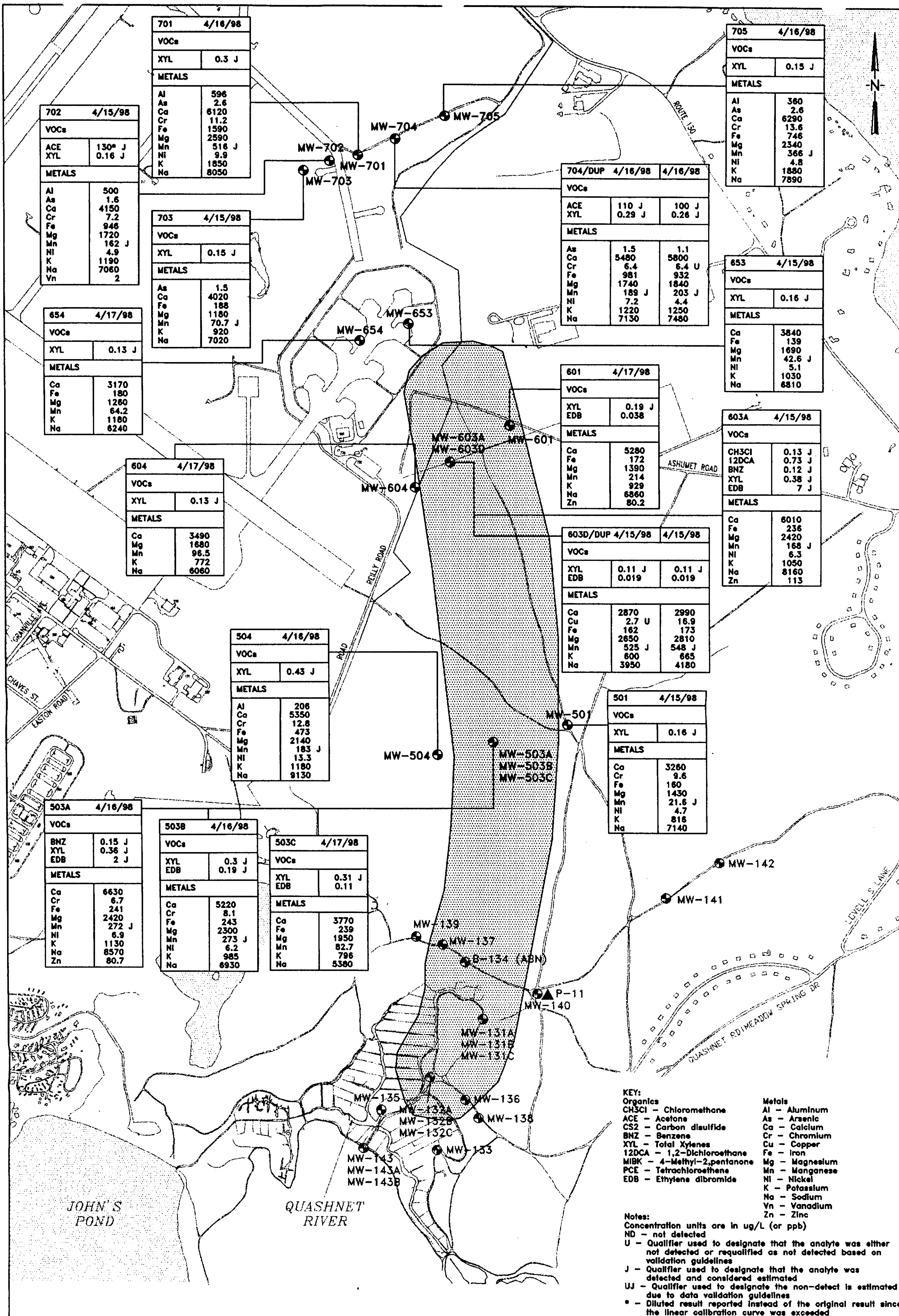

LEGEND

1997/1998 MONITORING WELL

EXISTNG PUMP TEST WELL

APPROXIMATE EDB PLUME

COMMODORE ADVANCED SCIENCES, INC.

SCALE IN FEET

800 400 0 400 800

FIGURE 2-5a
EXTENT OF EDB PLUME

AOC FS-1 Supplemental Remedial Investigation
Massachusetts Military Reservation

SCALE: 1"=800'	DWN BY: KVP
DATE: 5-13-99	FILENAME: MMR98AN2.DWG

TABLES

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Table 3.1 Summary of Samples Used for Human Health and Ecological Risk Assessment
Massachusetts Military Reservation
Fuel Spill 1

Sample #	Media Sampled	Analysis	Year Sampled
WM1	**Groundwater**	VOC, SVOC, INORGANICS	1987
WM1	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
WM10A	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
WM10B	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW11	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW112	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW112 & dup	Groundwater	VOC, SVOC, TPH, INORGANICS	1990
MW12	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW121	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW131A	Groundwater	VOC, EDB, INORGANICS	1997
MW131B	Groundwater	VOC, EDB, INORGANICS	1997
MW131C	Groundwater	VOC, EDB, INORGANICS	1997
MW132A & dup	Groundwater	VOC, EDB, INORGANICS	1997
MW132B & dup	Groundwater	VOC, EDB, INORGANICS	1997
MW132C	Groundwater	VOC, EDB, INORGANICS	1997
MW136	Groundwater	VOC, EDB, INORGANICS	1997
MW137	Groundwater	VOC, EDB, INORGANICS	1997
MW14 & dup	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW140	Groundwater	VOC, EDB, INORGANICS	1997
MW15131 & dup	Groundwater	VOC, SVOC, TPH, PEST, INORGANICS	1994
MW17	Groundwater	VOC, EDB, INORGANICS	1997
MW2	Groundwater	VOC, SVOC, INORGANICS	1988
MW2	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW4	Groundwater	VOC, SVOC, TPH, INORGANICS	1989; 1990
MW4A	Groundwater	VOC, SVOC, TPH, INORGANICS	1989; 1990
MW41	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW412	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW413	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW414	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW415	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW42	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW501	Groundwater	VOC, EDB, INORGANICS	1998
MW503A	Groundwater	VOC, EDB, INORGANICS	1998
MW503B	Groundwater	VOC, EDB, INORGANICS	1998
MW503C	Groundwater	VOC, EDB, INORGANICS	1998
MW504	Groundwater	VOC, EDB, INORGANICS	1998
MW516	Groundwater	VOC, PEST, INORGANICS	1987
MW517	Groundwater	VOC, PEST, INORGANICS	1987
MW538A & dup	Groundwater	VOC, SVOC, INORGANICS	1993
MW538B	Groundwater	VOC, SVOC, INORGANICS	1993
MW538C	Groundwater	VOC, SVOC, INORGANICS	1993
MW552A	Groundwater	VOC, SVOC, INORGANICS	1993
MW552B	Groundwater	VOC, EDB, INORGANICS	1997

Table 3.1 Summary of Samples Used for Human Health and Ecological Risk Assessment
Massachusetts Military Reservation
Fuel Spill 1 (continued)

Sample #	Media Sampled	Analysis	Year Sampled
MW552B & dup	Groundwater	VOC, SVOC, INORGANICS	1993
MW552C	Groundwater	VOC, SVOC, INORGANICS	1993
MW552C	Groundwater	VOC, EDB, INORGANICS	1997
MW552D	Groundwater	VOC, SVOC, INORGANICS	1993
MW553A	Groundwater	VOC, SVOC, INORGANICS	1993
MW553D	Groundwater	VOC, SVOC, INORGANICS	1993
MW556A	Groundwater	VOC, SVOC, INORGANICS	1993
MW556B	Groundwater	VOC, SVOC, INORGANICS	1993
MW568	Groundwater	VOC, SVOC, INORGANICS	1993
MW6	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW601	Groundwater	VOC, EDB, INORGANICS	1998
MW603A	Groundwater	VOC, EDB, INORGANICS	1998
MW603D & dup	Groundwater	VOC, EDB, INORGANICS	1998
NW604	Groundwater	VOC, EDB, INORGANICS	1998
MW653	Groundwater	VOC, EDB, INORGANICS	1998
MW654	Groundwater	VOC, EDB, INORGANICS	1998
MW7	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW701	Groundwater	VOC, EDB, INORGANICS	1998
MW702	Groundwater	VOC, EDB, INORGANICS	1998
MW703	Groundwater	VOC, EDB, INORGANICS	1998
MW704 & dup	Groundwater	VOC, EDB, INORGANICS	1998
MW705	Groundwater	VOC, EDB, INORGANICS	1998
MW8 & dup	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MW9	Groundwater	VOC, SVOC, TPH, INORGANICS	1990
MW9 & dup	Groundwater	VOC, SVOC, TPH, INORGANICS	1989
MWRFW11	Groundwater	VOC, SVOC, INORGANICS	1989
RFW011	Groundwater	VOC, SVOC	1989
36SW0001	Surface Water	EDB	1997; 1998
36SW0003	Surface Water	EDB	1997; 1998
36SW0014	Surface Water	EDB	1997; 1998
36SW0015	Surface Water	EDB	1997; 1998
36SW0019	Surface Water	EDB	1997; 1998
36SW002	Surface Water	VOC, SVOC, EDB, METALS	1997; 1998
36SW0021	Surface Water	EDB	1997; 1998
36SW0022	Surface Water	EDB	1997; 1998
36SW0023	Surface Water	EDB	1997; 1998
36SW0024	Surface Water	EDB	1997; 1998
36SW0025	Surface Water	EDB	1997; 1998
36SW0026	Surface Water	EDB	1997; 1998
36SW0027	Surface Water	EDB	1997; 1998
36SW0028	Surface Water	EDB	1997; 1998
36SW0029	Surface Water	EDB	1997; 1998
36SW003	Surface Water	EDB	1997; 1998
36SW0036	Surface Water	EDB	1997; 1998

Table 3.1 Summary of Samples Used for Human Health and Ecological Risk Assessment
Massachusetts Military Reservation
Fuel Spill 1 (continued)

Sample #	Media Sampled	Analysis	Year Sampled
36SW004	Surface Water	EDB	1997; 1998
36SW005	Surface Water	EDB	1997; 1998
36SW006	Surface Water	EDB	1997; 1998
36SW007 & dup	Surface Water	EDB	1997; 1998
36SW008	Surface Water	EDB	1997; 1998
36SW009	Surface Water	EDB	1997; 1998
36SW010	Surface Water	EDB	1997; 1998
36SW011	Surface Water	EDB	1997; 1998
36SW012	Surface Water	VOC, SVOC, EDB, METALS	1997; 1998
36SW013	Surface Water	EDB	1997; 1998
36SW016	Surface Water	VOC, SVOC, EDB, METALS	1997; 1998
36SW017	Surface Water	VOC, SVOC, EDB, METALS	1997; 1998
36SW018	Surface Water	VOC, SVOC, EDB, METALS	1997; 1998
36SW020	Surface Water	VOC, SVOC, EDB, METALS	1997; 1998
36SW0002	**Sediment**	VOC, SVOC, EDB, METALS	1998
36SW0012	Sediment	VOC, SVOC, EDB, METALS	1998
36SW0016	Sediment	VOC, SVOC, EDB, METALS	1998
36SW0017	Sediment	VOC, SVOC, EDB, METALS	1998
36SW0018	Sediment	VOC, SVOC, EDB, METALS	1998
36SW0020	Sediment	VOC, SVOC, EDB, METALS	1998
36DP01	**Surface Soil (0-2 ft)**	SVOC, PEST, METALS	1995
36SS50	Surface Soil (0-2 ft)	SVOC, PEST, METALS	1995
36SS51	Surface Soil (0-2 ft)	SVOC, PEST, METALS	1995
36SS52	Surface Soil (0-2 ft)	SVOC, PEST, METALS	1995
36SS53	Surface Soil (0-2 ft)	SVOC, PEST, METALS	1995
36SS54	Surface Soil (0-2 ft)	PEST, METALS	1995
FS1-TB4	Surface Soil (0-2 ft)	METALS	1988
FS1-TB4D	Surface Soil (0-2 ft)	METALS	1998
FS1-TB2	**Surface Soil (2-10 ft)**	VOC, METALS	1988
TS1-TB3	Surface Soil (2-10 ft)	VOC, METALS	1988

KEY:

MW = Monitoring Wells
VOC = Volatile Organic Compound
SVOC = Semivolatile Organic Compound
TPH = Total Petroleum Hydrocarbons
PEST = Pesticides
EDB = Ethylene dibromide

Table 3.2 Constituents of Potential Concern for Risk Analysis

Constituent	AOC Soil	Groundwater Plume	Surface water	Sediment
Volatile Organics				
1,2-Dichloroethane		x		x
4-Methyl-2-pentanone		x		
Chloroform		x	x	
Chloromethane		x		
1,2-Dibromoethane (EDB)		x	x	
Tetrachloroethene		x		
Toluene		x		
Pesticides/PCBs				
Alpha chlordane	x			
Endosulfan II	x			
Endrin Ketone	x			
Inorganics				
Aluminum		x	x	x
Arsenic	x	x		x
Barium			x	x
Beryllium				x
Boron			x	
Cadmium			x	
Chromium	x		x	x
Cobalt		x		x
Copper		x	x	x
Iron		x	x	x
Lead	x	x	x	x
Manganese		x	x	x
Nickel				x
Selenium				x
Silver		x		
Thallium		x		
Vanadium				x
Zinc	x			x

Table 3.3 Summary of Potential Human Health Exposure Scenarios
Massachusetts Military Reservation

Transport Medium/Location	Release Mechanism	Exposure Point	Potential Receptor	Exposure Route	Reason for Selection
AOC FS-1					
Soil/flightline area	Affected soil	Surface and subsurface soil	Utility Worker (Current & Future)	Ingestion, Inhalation, Dermal	Workers may be exposed during excavation activities.
Groundwater Plume and Upwelling Area					
Groundwater	Groundwater	Groundwater	Resident (Future)	Ingestion, Inhalation, Dermal	Potential contact through residential groundwater use
Groundwater	Surface Water and Sediment	Surface Water and Sediment	Cranberry Worker (Current & Future)	Ingestion, Inhalation, Dermal	Cranberry Workers may come into contact with contaminated surface water and sediments
Groundwater	Surface Water and Sediment	Surface Water and Sediment	Recreational Adult (Current & Future)	Ingestion, Inhalation, Dermal Fish Ingestion	Recreational Adults may come into contact with contaminated surface water and sediment and may also ingest affected fish
Groundwater	Surface Water and Sediment	Surface Water and Sediment	Recreational Youth (Current & Future)	Ingestion, Inhalation, Dermal	Recreational Youth may come into contact with contaminated surface water and sediment

Table 3.4 Human Health Risk Summary for the AOC and Groundwater Plume and Upwelling Area
Massachusetts Military Reservation

EXPOSURE PATHWAY		MEAN/CT Total Cancer	MEAN/CT COC Risk Drivers	MEAN/CT Total HI	MEAN/CT COC Risk Drivers	MAX/RME Total Cancer	MAX/RME COC Risk Drivers	MAX/RME Total HI	MAX/RME COC Risk Drivers
FS-1 AOC									
Future/Current - Soil									
	Ingestion	N/A		N/A		N/A		N/A	
	Inhalation	N/A		N/A		N/A		N/A	
	Dermal	N/A		N/A		N/A		N/A	
Total Utility Worker		N/A		N/A		N/A		N/A	
FS-1 DOWNGRADIENT IMPACT AREA									
Future/Current - Groundwater									
	Ingestion	3.E-04	EDB, Arsenic	4.E-01		8.E-03	Chloromethane, PCE, EDB, Arsenic,	5.E+00	Arsenic, Iron
	Inhalation	1.E-05	EDB	2.E+00	EDB	3.E-04	Chloromethane, Chloroform, EDB, 1,2-DCA	2.E+01	Chloroform, Toluene, EDB
	Dermal	4.E-04	EDB	1.E-02		9.E-03	PCE, EDB, Arsenic	4.E-01	
Total Resident Adult		6.E-04		3.E+00		2.E-02		2.E+01	
Current / Future - Cranberry Worker									
Surface Water	Ingestion	8.E-08		6.E-05		5.E-07		2.E-04	
	Inhalation	3.E-08		7.E-03		4.E-07		3.E-02	
	Dermal	3.E-07		6.E-05		2.E-06	EDB	1.E-04	
	Total	4.E-07		7.E-03		3.E-06		3.E-02	
Sediment	Ingestion	0.E+00		3.E-04		0.E+00		1.E-03	
	Dermal	0.E+00		2.E-05		0.E+00		5.E-05	
	Total	0.E+00		3.E-04		0.E+00		1.E-03	
Total Risk to Cranberry Workers		4.E-07		8.E-03		3.E-06		3.E-02	
Current / Future - Youth									
Surface Water	Ingestion	8.E-08		7.E-05		1.E-06	EDB	2.E-03	
	Inhalation	3.E-09		8.E-04		5.E-08		1.E-02	
	Dermal	5.E-08		5.E-06		9.E-07		8.E-05	
	Total	1.E-07		9.E-04		2.E-06		2.E-02	
Sediment	Ingestion	0.E+00		3.E-04		0.E+00		1.E-02	
	Dermal	0.E+00		3.E-05		0.E+00		2.E-03	
	Total	0.E+00		3.E-04		0.E+00		1.E-02	
Total Risk to Youth		1.E-07		1.E-03		2.E-06		3.E-02	
Current / Future - Adult Wader									
Surface Water	Ingestion	6.E-08		4.E-05		3.E-06	EDB	1.E-03	
	Inhalation	2.E-09		4.E-04		1.E-07		1.E-02	
	Dermal	7.E-08		4.E-06		3.E-06	EDB	7.E-05	
	Total	1.E-07		5.E-04		6.E-06		1.E-02	
Sediment	Ingestion	0.E+00		8.E-05		0.E+00		3.E-03	
	Dermal	0.E+00		1.E-05		0.E+00		3.E-04	
	Total	0.E+00		9.E-05		0.E+00		3.E-03	
Fish Ingestion	Ingestion	4.E-06	EDB	2.E-02		6.E-05	EDB	2.E-01	
Total Risk to Adult Wader		4.E-06		2.E-02		6.E-05		2.E-01	

CT = Central Tendency
RME = Reasonable Maximum Exposure

Table 3.5 Summary of Potential Ecological Exposure Scenarios

Receptor	Contaminated Media	Exposure Type	Exposure Route
AOC FS-1 : Terrestrial			
Plants	Surface Soil	Direct	Absorption
White-Footed Mouse	Surface Soil	Direct/Indirect	Ingestion
Northern Short-Tailed Shrew	Surface Soil	Direct/Indirect	Food Chain
Grasshopper Sparrow	Surface Soil	Direct/Indirect	Food Chain
Red Fox	Surface Soil	Indirect	Food Chain
Northern Cardinal	Surface Soil	Indirect	Food Chain
Downgradient Impact Area: Aquatic / Semiaquatic			
Bull Frog	Surface Water/ sediment	Direct	Ingestion/absorption
Brook Trout	Surface Water/ sediment	Direct	Ingestion/absorption
Eastern Box Turtle	Surface Water/ sediment	Direct/Indirect	Ingestion/food chain
Raccoon	Surface Water/ sediment	Direct/Indirect	Ingestion/food chain
Muskrat	Surface Water/ sediment	Direct/Indirect	Ingestion/food chain
Mallard Duck	Surface Water/ sediment	Direct/Indirect	Ingestion/food chain
Black-Crowned Night Heron	Surface Water/ sediment	Indirect	Ingestion/food chain
Osprey	Surface Water	Indirect	Food Chain

Table 3.6 Summary of Ecological Risk for the FS-1 AOC and The Groundwater Plume Upwelling Area

Receptor	Media	Maximum Hazard Index	Mean Hazard Index
AOC - Terrestrial			
Plants	surface soil	1.41	0.53
White-footed Mouse	surface soil	0.001	0.003
Northern Short-tailed Shrew	surface soil	0.08	0.05
Red fox	surface soil	NA	NA
Grasshopper Sparrow	surface soil	1	0.3
Cardinal	surface soil	NA	NA
Groundwater Plume Upwelling Area Semi-Aquatic			
Aquatic Invertebrates	surface water/sediment	18	8
Bull Frog[a]	surface water/sediment	2	1
Eastern box turtle	surface water/sediment	0.8	0.5
Brook Trout[a]	surface water/sediment	2	1
Muskrat	surface water/sediment	0.037	0.016
Raccoon	surface water/sediment	0.09	0.06
Mallard	surface water/sediment	NA	NA
Black-crowned night heron	surface water/sediment	0.02	0.01
Osprey[b]	surface water	0.8	0.3

a - Bull Frog and trout risks are calculated by comparing appropriate surface water and sediment benchmarks to site surface water and sediment concentrations, respectively.
b - Calculations for Osprey risk consider surface water exposure through fish ingestion only.
NA - not applicable. During screening, no HECs were exceeded and no COPC were identified for this receptor.

Table 3.7 Recommended Cleanup Goals for Groundwater Contaminants at FS-1

Contaminant	Cleanup Value	Source
Toluene	1,000 µg/L	USEPA MCL
EDB	0.02 µg/L	MMCL
Lead	15 µg/L	USEPA MCL
Thallium	2 µg/L	USEPA MCL

USEPA = United States Environmental Protection Agency
EDB = Ethylene dibromide
MCL = Maximum contaminant level
MMCL = Massachusetts Maximum Contaminant Level

Table 5-1. Screening of FS-1 COCs

Contaminant of Concern	10^{-6} REC (µg/L)	HI= 1 HEC (µg/L)	MCL/MEG (µg/L)	Max. Detection (µg/L)	FS COC? (Y/N)	Reason for selection or rejection.
Chloromethane	6.78	-	-	8	N	Eliminated because of low detection frequency
Chloroform	14	365	-	4	N	Eliminated because concentrations below risk-based screening value
1,2-Dichloroethene	0.94	-	-	0.73	N	Eliminated because concentrations below risk-based screening value
4-Methyl-2-pentanone	-	-	-	85	N	Eliminated because no toxicity values available
Toluene	-	7300	1000	2500	Y	**Retained** because concentrations above MCL/MEG
Tetrachloroethene	1.64	365	5	2	N	Eliminated because of limited number of detections
TPH	-	-		0.96	N	Eliminated because no toxicity values available
EDB	0.001002	-	0.02	7.7	Y	**Retained** because concentrations above risk based screening value
Aluminum	36600	-	50	4200	N	Eliminated because concentrations below risk-based screening value
Arsenic	0.057	11	50	21	N	Eliminated because of low detection frequency
Chromium	-	110	100	41	N	Eliminated because concentrations below risk-based screening value
Cobalt	-	2200	-	5.4	N	Eliminated because concentrations below risk-based screening value
Copper	-	1465	1300	17	N	Eliminated because concentrations below risk-based screening value
Iron	-	11000	300	22000	N	Eliminated because concentrations below risk-based screening value
Lead	-	-	15	160	Y	**Retained** because concentrations above MCL/MEG
Manganese	-	5125	50	1500	N	Eliminated because concentrations below risk-based screening value
Thallium	-	-	2	3.1	Y	**Retained** because concentrations above MCL/MEG

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Table 6.1. Technology and Process Option Screening, [illegible] Feasibility Study, Massachusetts Military Reservation

General Response Action	Remedial Technologies (process options)	Description	Comment
No Action	None	No action taken to reduce risk.	Potentially applicable
Limited/Institutional Actions	Institutional Controls	Implement local instruments (e.g., zoning, land use, surface water, and groundwater restrictions) to limit exposure to contaminated groundwater.	Potentially applicable
	Groundwater Monitoring	Perform water quality analyses to monitor contaminant concentrations and assess future environmental impacts and compliance with remedial action objectives.	Potentially applicable
	Potable Water Supply	Provide potable water to people/businesses residing in an affected area through bottled water, point-of-use treatment, or drinking water distribution systems.	Potentially applicable
	Natural Attenuation	Rely on documented naturally occurring attenuation processes in groundwater to reduce contaminant concentrations. Processes such as dilution, dispersion, volatilization, biodegradation, and adsorption will reduce concentrations in a predictable, reliable manner.	Potentially applicable in source area; not applicable for EDB.
Extraction	Interceptor Trenches	Trenches, drains, and piping are used to passively collect (by gravity flow) and potentially hydraulically contain groundwater. Trench installation is typically limited to a depth of ~40 ft.	Not applicable. For majority of the plume, the contamination depth is beyond the capability of available trenching equipment. At the bogs, trenching may be possible, but remedial actions at the bogs do not protect receptors from groundwater.
	Wells	Vertical wells are arranged and pumped in a fashion that preferentially extracts contaminated groundwater from the aquifer.	Potentially applicable
	Directional Wells	Directional wells are arranged and pumped in a fashion that preferentially extracts contaminated groundwater from the aquifer.	Potentially applicable. Technology may not be applicable to extraction based on location of contamination, but may be applicable for injection and in situ treatments.
No Treatment	No Treatment	Water would be discharged without treatment	Not applicable. No Treatment does not meet RAOs
Ex Situ Treatment	Air Stripping	Air stripping removes VOCs from extracted groundwater by contacting contaminated water with large volumes of air. Contaminants are transferred from the liquid phase to the gaseous phase. Off-gas may require further treatment to meet air regulations.	Not applicable. EDB is not a compound that is easily air stripped
	Filtration	A filter is used to remove total suspended solids and precipitated floc.	Not applicable. Experience at MMR indicates filtration not necessary

Table 6.1. Technology and Process Option Screening, FS-1 Feasibility Study, Massachusetts Military Reservation

General Response Action	Remedial Technologies (process options)	Description	Comment
No Action	None	No action taken to reduce risk.	Potentially applicable
Limited/Institutional Actions	Institutional Controls	Implement local instruments (e.g., zoning, land use, surface water, and groundwater restrictions) to limit exposure to contaminated groundwater.	Potentially applicable
	Groundwater Monitoring	Perform water quality analyses to monitor contaminant concentrations and assess future environmental impacts and compliance with remedial action objectives.	Potentially applicable
	Potable Water Supply	Provide potable water to people/businesses residing in an affected area through bottled water, point-of-use treatment, or drinking water distribution systems.	Potentially applicable
	Natural Attenuation	Rely on documented naturally occurring attenuation processes in groundwater to reduce contaminant concentrations. Processes such as dilution, dispersion, volatilization, biodegradation, and adsorption will reduce concentrations in a predictable, reliable manner.	Potentially applicable in source area; not applicable for EDB.
Extraction	Interceptor Trenches	Trenches, drains, and piping are used to passively collect (by gravity flow) and potentially hydraulically contain groundwater. Trench installation is typically limited to a depth of ~40 ft.	Not applicable. For majority of the plume, the contamination depth is beyond the capability of available trenching equipment. At the bogs, trenching may be possible, but remedial actions at the bogs do not protect receptors from groundwater.
	Wells	Vertical wells are arranged and pumped in a fashion that preferentially extracts contaminated groundwater from the aquifer.	Potentially applicable
	Directional Wells	Directional wells are arranged and pumped in a fashion that preferentially extracts contaminated groundwater from the aquifer.	Potentially applicable. Technology may not be applicable to extraction based on location of contamination, but may be applicable for injection and in situ treatments.
No Treatment	No Treatment	Water would be discharged without treatment	Not applicable. No Treatment does not meet RAOs.
Ex Situ Treatment	Air Stripping	Air stripping removes VOCs from extracted groundwater by contacting contaminated water with large volumes of air. Contaminants are transferred from the liquid phase to the gaseous phase. Off-gas may require further treatment to meet air regulations.	Not applicable. EDB is not a compound that is easily air stripped.
	Filtration	A filter is used to remove total suspended solids and precipitated floc.	Not applicable. Experience at MMR indicates filtration not necessary.

Table 6-1 (continued)

Ex Treatment (continued)	Activated Carbon Adsorption	Activated carbon adsorption is a physical separation process in which organic materials are removed from wastewater by adsorption (i.e., the attraction and accumulation of one substance onto another) onto granular activated carbon. It may also be used to reduce concentrations of gaseous phase organics produced by processes such as air stripping.	Potentially applicable
	Ultraviolet(UV)/Oxidation	UV/oxidation involves the simultaneous application of UV light and chemical oxidants to degrade (through oxidation) concentrations of aqueous organics. Ozone and hydrogen peroxide have been documented as chemical oxidants.	Not applicable. UV/oxidation more expensive than other viable treatment technologies.
	UV/Reduction	Chemically reduces VOCs/SVOCs in extracted groundwater through simultaneous application of UV light and a proprietary liquid catalyst.	Not applicable. UV/reduction more expensive than other viable treatment technologies.
	Reverse osmosis	Contaminants are removed from groundwater during passage through a membrane. At high pressures, the membrane allows water to pass through while contaminants are retained. The process produces a concentrated waste stream requiring further treatment.	Not applicable. Metals at insufficient concentration to merit this option.
	Resin Adsorption/Ion Exchange	Resin adsorption uses a sorptive removal mechanism and is typically used for organic contaminants. Resin can be regenerated by removing the contaminants with solvent. Regeneration of the exhausted resin would produce a concentrated waste stream requiring further treatment. In exchange is the process of exchanging selected dissolved ionic contaminants in groundwater with ions held by the ion exchange material. Ion exchange is typically used for inorganic contaminants/	Not applicable. This option is more expensive than other viable treatment technologies.
In Situ Treatment	Reactive Wall	A trench is excavated perpendicular to the flow of groundwater and backfilled with a reactive material. Alternatively, a funnel and gate system composed of injected grout funnel walls and injected reactive material may be created perpendicular to groundwater flow. As groundwater flows through the wall, contaminants are either degraded by or sorbed to the reactive material. The reactive material can be designed to address both organic and inorganic contaminants.	Not applicable. Experience at MMR has not been successful for installation of deep funnel and gate systems. Trenching equipment incapable of installing trench at locations protective of groundwater.
	Biological Treatment	Naturally occurring microorganisms are supplied with nutrients (e.g., oxygen, nitrogen) and the subsurface environment is managed to enhance the microorganisms' ability to degrade organics into less toxic and nontoxic byproducts through aerobic or anaerobic degradation processes.	Not applicable. Levels of contamination too low to sustain microorganisms.

Table 6-1 (continued)

In Situ Treatment (continued)	Co-metabolic Enhancement	Methane and nutrients are injected into a zone of groundwater contamination. Existing or introduced methanogenic bacteria utilize injected methane and co-metabolize halogenated contaminants.	Not applicable. Ability of technology to remediate to necessary levels suspect. Explosive nature of injected materials not compatible with long-term project. Questionable e if permitting necessary to inject exogenous bacteria into aquifer is possible.
	Air Sparging	Air is injected into the subsurface saturated zone. VOCs are stripped from the groundwater and rise through the subsurface with the air. Air sparging is typically combined with SVE so that contaminated vapors can be collected before reaching the ground surface.	Not applicable. Contaminated groundwater overlain by up to 100 ft of clean groundwater. Possible air sparging would contaminate clean water.
	Peroxide/iron Injection	A peroxide and iron solution is injected and circulated in the zone of contamination. The solution oxidizes organic compounds. Decomposition products would be bromine and carbon dioxide.	Not applicable. Variable results suggest technology may be incapable of reducing contaminants to acceptable levels. Permitting for injection may be difficult.
	Recirculating Wells	A vertical groundwater circulation cell is established by installing a double-screened well where one screen in used to extract water into the treatment well and the second screen is used to inject water back into the aquifer. The circulation cell mobilizes and transports contaminants to the well for in-well stripping and removal of gaseous-phase contamination. The wells can be managed to enhance in situ biological degradation.	Not applicable. Insufficient evidence at MMR that recirculating cells can be established.
Discharge	Groundwater Reinjection	Reinject treated groundwater using infiltration trenches or reinjection wells. Only groundwater meeting discharge limits (e.g., action levels) would be reinjected.	Potentially applicable.
	Surface Water Discharge	Discharge treated groundwater meeting discharge limits to an on-site surface water body.	Potentially applicable.
Containment	Berms	Build earthen structures to separate areas of upwelling contaminated groundwater from areas of upwelling uncontaminated water	Potentially applicable.

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Table 7.1. FS-1 Ground r Modeling Summary

Run Number	Alterna-tives	Date	Number of Extraction Wells	Number of Extraction Well Points Repre-senting an Interceptor Pipe	Number of Injection Wells	Number of Reinjection Well Points Representing a Reinjection Pipe	Hydraulic Information Total Extraction Rate (gpd)	Total Reinjec-tion Rate (gpd)	% of Total Mass Captured	Plume Seeds	Notes
Stage 1 FS-1 Modeling											
1		10/1/98	0	0	0	0	0	0	0	4,673	No Action Scenario. Uniform discretization in X and Y directions (75-ft spacing).
2		10/7/98	40 (axial wells)	0	0	0	439.0	0	50	4,673	Axial well fence along center of plume. Maximum drawdown = 0.7 ft.
3		10/8/98	26 (total wells)	0	0	0	296.5	0	30	4,673	Three well fences perpendicular to direction of plume with five additional wells in the K-1 and K-2 bog areas.
4		10/8/98	21 (total wells)	0	0	0	280.0	0	17	4,673	Two small well fences and another larger well fence perpendicular to direction of plume with an axial fence in the K-2 and K-2 bog areas.
5	3[a]	10/9/98	40 (axial wells)	0	0	0	622.5	0	70	4,673	Same configuration as Run 2 with a higher total pumping rate. Maximum drawdown >0.8 ft.
6		10/9/98	27 (total wells)	0	0	0	565.0	0	56	4,673	Same configuration as Run 3 with a higher total pumping rate.
7	3[a]	10/9/98	23 (axial wells)	0	0	0	997.5	0	77	4,673	A variation on Run 5 with fewer wells and a higher total pumping rate. Maximum drawdown >1.25 ft.
Stage 2 FS-1 Modeling											
8		11/3/98	0	0	0	0	0	0	0	250	No Action scenario. Rediscretized to focus on the K-1 and K-2 bog areas. Smaller plume seeding limited to K-1 and K-2 areas.
9		11/4/98	1	0	0	11	200	100	30	250	Pumping EW-05 (screen -40 to -100) at 200 gpm with reinjection evenly spread among 11 well points representing the reinjection pipe north of the K-1 bog.
10		11/4/98	1	0	0	11	400	200	33	250	Pumping EW-05 at 400 gpm with same reinjection configuration but higher rate.
11		11/5/98	1	0	0	11	600	300	38	250	Pumping EW-05 at 600 gpm with same reinjection configuration but higher rate.

							Hydraulic Information				
Run Number	Alterna-tives	Date	Number of Extraction Wells	Number of Extraction Well Points Repre-senting an Interceptor Pipe	Number of Injection Wells	Number of Reinjection Well Points Representing a Reinjection Pipe	Total Extraction Rate (gpd)	Total Reinjec-tion Rate (gpd)	% of Total Mass Captured	Plume Seeds	Notes
Stage 2 FS-1 Modeling (continued)											
12		11/11/98	1	0	0	11	200	200	28	250	Same configuration as Run 9 with the screened interval lowered to -90 to -150. Reinjection of all extracted water.
13		11/11/98	1	26	0	11	500	200	91	250	Same configuration as Run 12 with addition of an interceptor pipe 10 ft below water table pumped at 300 gpm and represented by well points.
14		11/12/98	1	26	0	11	500	200	88	250	Same configuration as above with interceptor pipe (well points) 30 ft below water table pumped at 300 gpm.
15		11/13/98	1	26	0	11	600	200	92	250	Same configuration as above with interceptor pipe (well points) 10 ft below water table pumped at 400 gpm.
Stage 3 FS-1 Modeling											
16		1/29/99	0	0	0	0	0	0	0	44,824	No Action scenario. Rediscretized to account for addition of axial well fence from Run 7. New plume seeds.
17	2b	1/29/99	1	45	0	19	600	200	70	44,824	Refinement of Run 15 with new location of reinjection pipe north of the K-1 bog and the interceptor pipe.
18	3b	2/1/99	18 (axial wells)	45	0	19	1,000	200	85	44,824	Same configuration as Run 17 with addition of the 17 northernmost axial wells from Run 7 pumped at 23.5 gpm instead of 37.5 gpm.
19		2/2/99	18 (axial wells)	45	4	19	1,000	600	85	44,824	Same configuration as Run 18 with addition of 2 reinjection wells flanking each side of the plume above the K-1 bog.
20		2/19/99	18 (axial wells)	45	4	19	1,000	600	85	44,824	Same configuration as Run 19 with P-11 well activated at 350 gpm after 10 years.
21		2/19/99	1	45	0	19	600	200	73	44,824	Same configuration as Run 17 with P-11 well activated at 350 gpm after 10 years.

[a] Runs 5 and 7 combined for conceptual design of Alternative 3.

Table 8.1. Applicable or Relevant and Appropriate Requirements, Criteria, Advisories, and Guidance for AOC FS-1 Feasibility Study, Massachusetts Military Reservation

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
Chemical-specific Requirements Federal			
Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs) [40 *Code of Federal Regulations* (CFR) 141.11–141.16]	Relevant and Appropriate	MCLs have been promulgated for several common organic and inorganic contaminants. These levels regulate the concentration of contaminants in public drinking water supplies; they may also be considered relevant and appropriate for groundwater aquifers used for drinking water.	**Alternative 1**: No action will be taken. Plume is expected to attain MCLs in 11 years. **Alternative 2B:** The groundwater will be extracted, treated, and reinjected/discharged. The plume is expected to attain MCLs within 11 years. **Alternatives 3 and 3B**: The groundwater will be extracted, treated, and reinjected/discharged. The plume is expected to attain MCLs within 7 years.
Cancer slope factors (CSFs) (1997)	To Be Considered	CSFs are accepted input values to risk assessments that represent current cancer risks of compounds and elements.	**Alternatives 1, 2B, 3, and 3B**: CSFs were used in the risk assessment to develop remediation goals.
Integrated Exposure Uptake Biokinetic model for lead in children. U.S. Environmental Protection Agency (USEPA) publication 92857.7–15.2	To Be Considered	This model is used to assess the chronic, noncancer exposure of children to lead.	**Alternatives 1, 2B, 3, and 3B**. The model was used in the risk assessment to develop the cleanup standard for lead.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
Chemical-specific Requirements (continued) State Massachusetts Drinking Water Standards [310 *Code of Massachusetts Regulations* (CMR) 22.00]	Relevant and Appropriate	These regulations establish state drinking water standards (MMCLs) for public water systems. The state level for ethylene dibromide (EDB) [0.02 part per billion (ppb)] is more stringent than the federal level (0.05 ppb).	**Alternative**: No action will be taken; plume is expected to attain MMCLs in 11 years **Alternative 2B**: The groundwater will be extracted, treated, and reinjected/discharged. The plume is expected to attain MMCLs within 11 years. **Alternatives 3 and 3B**: The groundwater will be extracted, treated, and reinjected/discharged. The plume is expected to attain MMCLs within 7 years.
Massachusetts Groundwater Quality Standards (314 CMR 6.00)	Applicable	These standards limit the concentration of certain materials allowed in classified Massachusetts waters. The groundwater beneath and in the vicinity of MMR has been classified as Class I water (fresh groundwater found in the saturated zone of unconsolidated deposits) and is designated as a source of potable water supply.	**Alternative 1**: No action taken. No water reinjected into the aquifer **Alternatives 2B, 3, and 3B**: The ETR systems will be designed and operated to treat groundwater to obtain groundwater quality standards prior to reinjection
Massachusetts Surface Water Quality Standards (314 CMR 4.0)	Applicable	These standards mandate protection of surface water and regulate discharges to surface water. The Quashnet River bogs are Class B (habitat for fish, other aquatic life, and wildlife, and for primary and secondary recreation and are suitable for public water supply).	**Alternative 1**: No action taken. No water discharged to surface water. **Alternatives 2B, 3, and 3B**: The ETR systems will be designed and operated to treat groundwater prior to discharge to surface water such that surface water standards are met.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
Location-specific Requirements Federal			
Rivers and Harbors Act of 1899 (33 USC 403; 33 CFR Parts 320.323	Applicable	Section 10 of the Rivers and Harbors Act of 1899 requires authorization from the Secretary of the Arm, acting through the Corps of Engineers, for the construction of any structure in or over and "navigable water of the U.S." It also requires such authorization for the excavation from or deposition of material in such waters, or any obstruction or alteration in such waters.	**Alternative 1**: Not applicable. **Alternatives 2B, 3, and 3B**: All actions within navigable waters will be coordinated with the Army Corps of Engineers
Protection of Wetlands Executive Order (EO) 11990 (40 CFR Part 6, Appendix A)	Applicable	Appendix A of 40 CFR 6 sets forth USEPA policy for carrying out the provisions of the Wetlands EO (11990). Federal agencies are required to minimize the destruction, loss, or degradation of wetlands and to preserve and enhance natural and beneficial values of wetlands. Appendix A requires that no remedial alternatives adversely impact a wetland if another practicable alternative is available. If no alternative is available, effects from implementing the chosen alternative must be mitigated.	**Alternative 1**: No actions will be performed that may impact the wetland. **Alternatives 2B, 3, and 3B**: Remedial actions will be performed in such a manner that wetland areas are not adversely impacted. Altered areas will be repaired or restored.
Clean Water Act (CWA) Section 404; 40 CFR Part 230; 33 CFR Parts 320-323; 33 USC 1344	Applicable	No activity that adversely affects a wetland shall be permitted if a practicable alternative with less effects is available. If no practicable alternative exists, impacts must be mitigated.	**Alternative 1**: No actions will be performed that may impact the wetland. **Alternatives 2B, 3, and 3B**: Design, installation, and operation of the treatment and discharge systems are being undertaken to minimize impacts to wetlands. All impacts will be mitigated.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
Location-specific Requirements Federal (continued)			
Fish and Wildlife Coordination Act (16 USC 661; 40 CFR 6.302)	Applicable	This act requires that any federal agency proposing to modify a body of water must consult with the U.S. Fish and Wildlife Service, National Marine Fisheries Service, and other related state agencies to develop measures to prevent, mitigate, or compensate to project-related losses to fish and wildlife. Such action should be viewed in the context of obtaining maximum overall project benefits such as cleaning up the site. The requirements to comply with this Act are contained in EPA's NPDES permit regulations (40 CFR 122.49)	**Alternative 1**: No actions will be performed that involve the body of water. **Alternatives 2B, 3, and 3B:** Actions will be taken to develop measures to prevent, mitigate, or compensate for project-related impacts to fish and wildlife. Relevent agencies will be contacted to help analyze the impact on fish and wildlife from installing treatment systems and discharging treated water to the Quashnet River.
Floodplain Management EO 11988 (40 CFR Part 6, Appendix A).	Applicable	This order requires federal agencies to minimize potential harm to or within floodplains and avoid floodplain development wherever there is a practicable alternative.	**Alternative 1**: No actions will be taken that impact floodplains. **Alternatives 2B, 3, and 3B**: All activities within the wetlands and buffer zones will be conducted to meet all requirements. If remedial actions alter more than 5000 square feet of protected area, the affected area will be restored within two growing seasons.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
State			
Massachusetts Wetlands Regulations (310 CMR 10.00)	Applicable	These regulations protect inland and coastal wetlands as well as a 100-ft buffer zone from activities that may alter the resource area. Some wetlands receive additional protection of wildlife. The protected habitats are defined by the presence of particular plant or animal communities and/or hydrologic characteristics. The regulations specifically prohibit the loss of over 5,000 square feet of bordering vegetated wetlands. The loss may be permitted with replication of the lost area within two growing seasons.	**Alternative 1**: No actions will be performed that may impact the protected wetland. **Alternatives 2B, 3, and 3B:** All activities within the wetland area and buffer zones will be conducted to meet all requirements. If remedial actions alter more that 5,000 square feet, the affected area will be restored within two growing seasons.
Massachusetts Endangered Wildlife and Wild Plants (321 CMR 8.00)	Applicable	The Commonwealth of Massachusetts has authority to research, list, and protect any species deemed endangered, threatened, or of special concern. These species are listed as either endangered, threatened, or species of special concern in the regulations. The Massachusetts list may differ from the federal lists of endangered species. Actions must be conducted in a manner that minimizes the effect on Massachusetts-listed endangered species and species listed by the Massachusetts Natural Heritage Program.	**Alternative 1**: No actions will be performed that may impact these protected species. **Alternatives 2B, 3, and 3B**: Several state-listed species have been identified in the vicinity of MMR. Areas in which work is to be conducted will be evaluated for the presence of habitat for endangered or threatened species. Activities will be designed to meet the requirements of these regulations.
Action-specific Requirements Federal			
Underground Injection Control Program (40 CFR 144, 146,147, 1000)	Applicable	These regulations outline minimum program and performance standards for underground injection programs.	**Alternative 1**: No remedial actions would occur to trigger these regulations. **Alternatives 2B, 3, and 3B**: Extracted groundwater will be treated to levels at or below federal and state drinking water standards to ensure that discharges to infiltration galleries will not cause any violation of drinking water standards in the receiving aquifer.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
National Pollutant Discharge Elimination System (NPDES) (40 CFR 122-125 and 131)	Applicable	Establishes discharge limitations, monitoring requirements, and best management practices for any direct discharge from a point source into surface water.	**Alternative 1:** No remedial actions would occur to trigger this requirement. **Alternatives 2B, 3, and 3B:** Discharge of treated water into the Quashnet River or cranberry bogs will meet these standards.
RCRA – Identification and Listing of Hazardous Wastes; Toxicity Characteristics (40 CFR Part 261.24)	Relevant and Appropriate	These requirements identify the maximum concentrations of contaminants for which the waste would be a RCRA characteristic waste for toxicity. The analytical test given in Appendix II is referred to as the TCLP.	**Alternative 1:** Not applicable. **Alternatives 2B, 3, and 3B:** Drill cuttings, spent activated carbon, and sludge sent off-site for disposal (not including regeneration) will be analyzed according to TCLP. If TCLP results exceed standards in 40 CFR 261.24, the material will be disposed of off-site in a RCRA-permitted treatment, storage, and disposal facility.
Resource Conservation and Recovery Act (RCRA) Air Emission Standards for Process Vents (40 CFR 264, Subpart AA)	Relevant and Appropriate	These regulations establish requirements for controlling emissions from process vents associated with treatment processes that manage hazardous wastes with organic concentrations of 10 ppm or more.	**Alternative 1:** Not applicable. **Alternatives 2B, 3, and 3B:** If thresholds are met, emissions from process vents will be controlled in accordance with these requirements.
Action-specific Requirements (continued) Federal (continued) Standards for Control of Emissions of Volatile Organic Compounds (VOCs), RCRA (40 CFR 264, Subpart BB)	Relevant and Appropriate	Contains air pollutant emissions standards for equipment leaks at hazardous waste treatment, storage, and disposal (TSD) facilities. Contains design specifications and requirements for monitoring for leak detection. It is applicable to equipment that contains hazardous wastes with organic concentrations of at least 10% by weight.	**Alternative 1:** No remedial actions would occur that would trigger these standards. **Alternatives 2B, 3, and 3B:** If treatment involves groundwater with organic concentration of at least 10% by weight, equipment will meet the design specifications and will be monitored for leaks.
RCRA Subtitle C (40 CFR 264), Standards for Owners and Operators of Hazardous Waste TSD Facilities	Relevant and Appropriate	These standards, which regulate the operation of facilities that treat, store, or dispose of hazardous waste, take effect through authorized state RCRA programs sited below.	**Alternative 1:** Not applicable. **Alternatives 2B, 3, and 3B:** See Massachusetts hazardous waste regulations cited below.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
RCRA Subtitle C Subpart F – releases from Solid Waste Management Units	Relevant and Appropriate	These regulations establish groundwater protection requirements, including monitoring.	**Alternative 1:** Not applicable. **Alternatives 2B, 3, and 3B:** The groundwater will be monitored in accordance w1th these standards.
State			
Massachusetts Department of Public Health Food Tolerance Action Levels (105 CMR 515.00)	To Be Considered	Establishes food tolerance action levels for EDB.	**Alternative 1:** No actions will be taken. **Alternatives 2B, 3, and 3B:** The FS-1 treatment system and additional actions to be taken at the cranberry bogs will minimize the possibility that concentration of EDB exceeding the food tolerance action levels are present in the cranberry crop. Cranberries will be sampled and analyzed as an additional measure of the performance of the alternative.
Action-specific Requirements (continued) State (continued)			
Massachusetts Underground Water Source Protection (310 CMR 27)	Applicable	Under these regulations, "No underground injection shall be allowed where a Class V well causes or allows movement of fluid containing any pollutant into underground sources of drinking water and the presence of such a pollutant causes or is likely to cause a violation of any Massachusetts Drinking Water Regulation…or…adversely affects or is likely to adversely affect the health of persons." Class V wells are defined to include, "wells used to replenish the water in an aquifer."	**Alternative 1:** No actions will occur that will trigger these requirements. **Alternatives 2B, 3, and 3B:** Extracted groundwater will be treated to levels at or below federal and state drinking water standards to ensure that discharges to the aquifer will not cause any violation of drinking water standards in the receiving aquifer.
Massachusetts Underground Injection Control Regulations (310 CMR 27)	Applicable	These regulations prohibit the injection of hazardous waste into groundwater to protect the source of drinking water.	**Alternative 1:** No actions will occur that will trigger these requirements. **Alternatives 2B, 3, and 3B:** Reinjection wells for the ETR system will be designed to meet these standards.
Massachusetts Groundwater Discharge Permits (314 CMR 5.00)	Applicable	Establishes permit system for permitting of discharges to groundwater.	**Alternative 1:** No actions will occur that will trigger these requirements. **Alternatives 2B, 3, and 3B:** Injection wells will be designed to meet these standards and permitting requirements.

Requirement	Status	Requirement Synopsis	Action To Be Taken To Attain Requirement
Massachusetts Air Pollution Control Regulations (310 CMR 7.00)	Applicable	These regulations set emission limits necessary to attain ambient air quality standards.	**Alternative 1:** No actions will occur that trigger these requirements. **Alternatives 2B, 3, and 3B:** Construction activities and on-site treatments will be performed to meet the standards for visible emissions (310 CMR 7.06); dust, odor, construction, and demolition compounds (310 CMR 7.09); noise (310 CMR 7.10) and VOCs (310 CMR 7.18). If standards are exceeded, emissions will be managed through engineering controls.
Massachusetts Hazardous Waste Management Regulations (HWMR) - Requirements for Generators (310 CMR 30.300-30.371)	Relevant and Appropriate	This requirement sets standards for generators of hazardous waste that address (1) accumulating waste, (2) preparing waste for shipment, and (3) preparing the hazardous waste manifest. Massachusetts specifies requirements for very small quantity generators as well as small- and large-quantity generators.	**Alternative 1:** No actions will occur to trigger these rules. **Alternatives 2B, 3, and 3B:** If RCRA-characteristic wastes are generated, the material will be managed in accordance with these requirements .
Massachusetts HWMR – Location Standards (310 CMR 30.300-30.700-30.707)	Relevant and Appropriate	Under these standards, a new facility may not be located in an area subject to flooding; within the watershed of a Class A or Class SA segment of the surface water body unless it is determined that there is no feasible alternative; on land overlying an actual, planned, or potential public of private drinking water source; or in the flow path of groundwater supplying water to an existing well. In addition, there shall be a minimum of 300 feet from the active portion of the facility to the facility property line.	**Alternative 1:** No actions will occur to trigger these rules. **Alternatives 2B, 3, and 3B:** Any treatment facility will be located and operated to fulfill these regulations unless there is no feasible alternative. A waiver may be requested for the distance from the treatment facility to the property line.

See notes on following page.

ARAR	applicable or relevant and appropriate requirement
CFR	*Code of Federal Regulations*
CMR	*Code of Massachusetts Regulations*
CSF	cancer slope factor
CWA	Clean Water Act
EDB	ethylene dibromide
EO	Executive Order
HWMR	Hazardous Waste Management Regulations
MCL	maximum contaminant level
NPDES	National Pollutant Discharge Elimination System
OSWER	Office of Solid Waste and Emergency Response (USEPA)
ppb	part per billion
RCRA	Resource Conservation and Recovery Act
SDWA	Safe Drinking Water Act
TCLP	Toxic Compound Leaching Procedure
TSD	treatment, storage, and disposal
USC	United States Code
USEPA	U.S. Environmental Protection Agency
VOC	volatile organic compound

Table 9-1. Comparative Analysis of Alternatives for FS-1 Feasibility Study

General Response Action Criteria	Alternative 1 No Action	Alternative 2b Limited Action with Leading Edge Extraction, Treatment and Reinjection/Discharge	Alternative 3 Axial Well Extraction, Treatment, and Reinjection/Discharge	Alternative 3B Axial and Leading Edge Extraction, Treatment, and Reinjection/Discharge
Overall Protection of Human Health and the Environment	Least protective; will not achieve RAOs for 11 years. Does not protect human health or the environment during that 11 years.	Moderately protective; uses institutional actions to protect until remedial action restores groundwater and surface water to acceptable standards. Surface water RAOs will be achieved within 1 year. Groundwater RAOs achieved in 11 years.	More protective; uses institutional actions to protect until remedial action restores groundwater and surface water to acceptable standards. Surface water RAOs will be achieved within 1 year. Groundwater RAOs achieved in 7 years.	Most protective; uses institutional actions to protect until remedial action restores groundwater and surface water to acceptable standards. Surface water RAOs will be achieved within 1 year. Groundwater RAOs achieved in 7 years.
Compliance with ARARS	Complies with ARARS.	Complies with ARARS Will achieve chemical-specific ARARS in 11 years	Complies with ARARS. Will achieve chemical-specific ARARS in 7 years.	Complies with ARARS. Will achieve chemical-specific ARARS in 7 years.
Long-term Effectiveness and Permanence	Will achieve RAOs; is effective and is permanent.	Good long-term effectiveness; will achieve RAOs in 11 years. No risk after implementation complete. At 11 years: 68% EDB extracted by treatment system 18% EDB escapes extraction and discharges 14% EDB remains in aquifer retained on silts and in dead end pores. P-11 not impacted by system	Good long-term effectiveness; will achieve RAOs in 7 years. No risk after implementation complete. At 7 years: 83% EDB extracted by treatment system 11% EDB escapes extraction and discharges 6% EDB remains in aquifer retained on silts and in dead end pores P-11 not impacted by system	Good long-term effectiveness; will achieve RAOs in 7 years. No risk after implementation complete. At 7 years: 83% EDB extracted by treatment system 11% EDB escapes extraction and discharges 6% EDB remains in aquifer retained on silts and in dead end pores. P-11 not impacted by system.
Reduction of Toxicity, Mobility, and/or Volume Through Treatment	No reduction in toxicity, mobility, and/or volume; does not satisfy preference for treatment.	Reduces toxicity, mobility, and volume through treatment. EDB MCL of 0.02 $\mu g/L$ achieved. Achieves reduction after startup. Bog separation aspect is operational.	Better reduction of toxicity, mobility, and/or volume through treatment. EDB MCL of 0.02 $\mu g/L$ achieved. Achieves reduction after system startup. System cannot be started before 2000.	Maximizes reduction of toxicity, mobility, and/or volume through treatment. EDB MCL of 0.02 $\mu g/L$ achieved. Achieves reduction after startup. Bog separation aspect is operational.
Short-term Effectiveness	Does not decrease short-term risk. Community and environment not protected. No risk to workers. RAOs achieved in 11 years	Good short-term effectiveness. Protects human health and the environment. Construction and treatment plant workers may be exposed to contamination. Community protected during implementation. Environmental impacts mitigated through engineering practices and environment protected by extraction of groundwater. RAOs achieved in 11 years.	Good short-term effectiveness. Protects human health and the environment. Construction and treatment plant workers may be exposed to contamination. Community protected during implementation. Environmental impacts mitigated through engineering practices and environment protected by extraction of groundwater. RAOs achieved in 7 years.	Good short-term effectiveness. Protects human health and the environment. Construction and treatment plant workers may be exposed to contamination. Community protected during implementation. Environmental impacts mitigated through engineering practices and environment protected by extraction of groundwater. RAOs achieved in 7 years.
Implementability	Most easily implemented and will not interfere with future remedial actions.	Difficult to implement; however, similar activities are common groundwater cleanup activities. Technology is reliable. Future remedial activities not impacted by alternative.	More difficult to implement; however, similar activities are common groundwater cleanup activities. Technology is reliable. Future remedial activities not impacted by alternative.	Most difficult to implement; however, similar activities are common groundwater cleanup activities. Technology is reliable. Future remedial activities not impacted by alternative.
Cost				
Capital cost	$0	$3,952,000	$4,626,000	$6,385,000
Annual O&M Costs	$0	$394,000	$480,000	$514,000
Present Worth	$0	$9,423,000	$8,699,000	$10,561,000

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APPENDIX A
CHEM BOX FIGURES FROM FS-1 INVESTIGATIONS

SS-51	Conc.
SVOCs	**ug/kg**
Phenanthrene	100
Anthracene	ND
Fluoranthene	180
Pyrene	270
Benzo(a)anthracene	90
Chrysene	ND
Benzo(b)fluoranthene	210
Benzo(k)fluoranthene	190
Benzo(a)pyrene	100
Indeno(1,2,3-cd)pyrene	49
Benzo(g,h,i)perylene	44
Acenaphthlene	ND
PESTICIDES	**ug/kg**
alpha-BHC	ND
Aldrin	ND
Heptachlor epoxide	0.29
Endosulfan I	0.6
Dieldrin	1.5
4,4'-DDE	ND
Endrin	0.92
Endosufan II	1.4
4,4'-DDD	ND
4,4'-DDT	0.24
Methoxychlor	ND
Endrin ketone	ND
alpha-Chlodane	0.16
gamma-Chlordane	ND
METALS	**mg/Kg**
Aluminum	931
Antimony	ND
Arsenic	ND
Barium	11.5 J
Chromium	2.4
Cobalt	0.98
Iron	1770
Lead	8.4
Magnesium	225
Manganese	42.4
Nickel	1.9
Potassium	98.7 J
Sodium	272 J
Vanadium	2.9
MISCELLANEOUS	**mg/Kg**
TOC	NA

SS-52	Conc.	DUP
SVOCs	**ug/kg**	**ug/kg**
Phenanthrene	76	56
Anthracene	ND	12
Fluoranthene	140	130
Pyrene	230	210
Benzo(a)anthracene	130	110
Chrysene	180	170
Benzo(b)fluoranthene	370	270
Benzo(k)fluoranthene	330	250
Benzo(a)pyrene	190	190
Indeno(1,2,3-cd)pyrene	ND	130
Benzo(g,h,i)perylene	ND	150
Acenaphthlene	50	ND
PESTICIDES	**ug/kg**	**ug/kg**
alpha-BHC	ND	ND
Aldrin	ND	0.16
Heptachlor epoxide	ND	ND
Endosulfan I	0.74	ND
Dieldrin	1.8	1.6
4,4'-DDE	0.28	0.24
Endrin	0.87	0.76
Endosufan II	0.97	ND
4,4'-DDD	ND	ND
4,4'-DDT	0.81	1
Methoxychlor	ND	ND
Endrin ketone	ND	0.34
alpha-Chlodane	0.24	0.19
gamma-Chlordane	ND	ND
METALS	**mg/Kg**	**mg/Kg**
Aluminum	1790	1800
Antimony	ND	ND
Arsenic	0.93	1.2
Barium	5.1 J	5.1 J
Chromium	3.5	3.2
Cobalt	0.99	1
Iron	3370	3220
Lead	41.4	36.6
Magnesium	387	393
Manganese	31.5	29.7
Nickel	2	1.9
Potassium	161	176 J
Sodium	253	258 J
Vanadium	5.6	5.3
MISCELLANEOUS	**mg/Kg**	**mg/Kg**
TOC	50	NA

NOTES:

J = Estimated

NA = Not Analyzed

ND = Non Detect

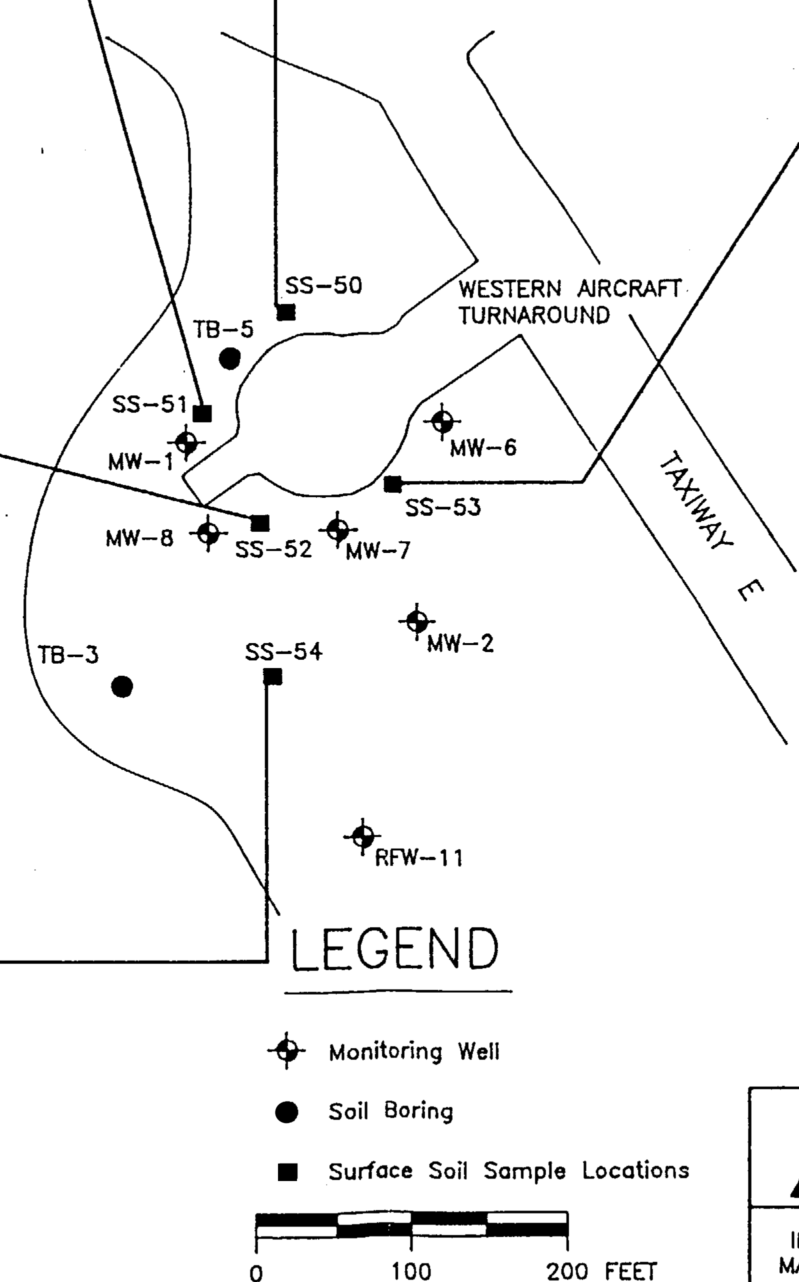
TOC = Total Organic Carbon

Conc. = Concentrations

• = Indicates duplicate analysis is not within control limits.

SS-53	Conc.
SVOCs	**ug/kg**
Phenanthrene	150
Anthracene	ND
Fluoranthene	140
Pyrene	220
Benzo(a)anthracene	53
Chrysene	240
Benzo(b)fluoranthene	360
Benzo(k)fluoranthene	320
Benzo(a)pyrene	140
Indeno(1,2,3-cd)pyrene	79
Benzo(g,h,i)perylene	ND
Acenaphthlene	54
PESTICIDES	**ug/kg**
alpha-BHC	0.23
Aldrin	ND
Heptachlor epoxide	0.48
Endosulfan I	0.59
Dieldrin	13
4,4'-DDE	1
Endrin	1.7
Endosufan II	1.5
4,4'-DDD	3
4,4'-DDT	3.2
Methoxychlor	0.72
Endrin ketone	ND
alpha-Chlodane	0.35
gamma-Chlordane	0.15
METALS	**mg/Kg**
Aluminum	2690
Antimony	0.63 J
Arsenic	1.2
Barium	4.6 J
Chromium	7.4
Cobalt	0.87
Iron	3740
Lead	114
Magnesium	404
Manganese	24.9
Nickel	2.7
Potassium	165 J
Sodium	255 J
Vanadium	8.2
MISCELLANEOUS	**mg/Kg**
TOC	NA

SS-50	Conc.
SVOCs	**ug/kg**
Phenanthrene	61
Anthracene	ND
Fluoranthene	75
Pyrene	110
Benzo(a)anthracene	52
Chrysene	72
Benzo(b)fluoranthene	110
Benzo(k)fluoranthene	100
Benzo(a)pyrene	59
Indeno(1,2,3-cd)pyrene	ND
Benzo(g,h,i)perylene	ND
Acenaphthlene	ND
PESTICIDES	**ug/kg**
alpha-BHC	ND
Aldrin	ND
Heptachlor epoxide	0.15
Endosulfan I	ND
Dieldrin	1.9
4,4'-DDE	2.1
Endrin	0.47
Endosufan II	1
4,4'-DDD	ND
4,4'-DDT	5
Methoxychlor	ND
Endrin ketone	0.53
alpha-Chlodane	0.24
gamma-Chlordane	ND
METALS	**mg/Kg**
Aluminum	1590
Antimony	ND
Arsenic	0.67
Barium	64.8 J
Chromium	3
Cobalt	0.69
Iron	2370
Lead	23.6
Magnesium	290
Manganese	23.6
Nickel	1.6
Potassium	107 J
Sodium	259 J
Vanadium	3.7
MISCELLANEOUS	**mg/Kg**
TOC	50



TB-4	Conc.	DUP
VOCs	**ug/kg**	**ug/kg**
Chlorothane	ND	ND
Acetone	ND	ND
Methylene Chloride	ND	ND
Metals	**mg/kg**	**mg/kg**
Aluminum	982 •	1310 •
Chromium	ND	2.8
Iron	1600 •	2500 •
Lead	1.3	1.9
Manganese	49	91
Zinc	7.1 •	7.6 •

SS-54	Conc.
SVOCs	**ug/kg**
Phenanthrene	ND
Anthracene	ND
Fluoranthene	ND
Pyrene	ND
Benzo(a)anthracene	ND
Chrysene	ND
Benzo(b)fluoranthene	ND
Benzo(k)fluoranthene	ND
Benzo(a)pyrene	ND
Indeno(1,2,3-cd)pyrene	ND
Benzo(g,h,i)perylene	ND
Acenaphthlene	ND
PESTICIDES	**ug/kg**
alpha-BHC	ND
Aldrin	ND
Heptachlor epoxide	ND
Endosulfan I	ND
Dieldrin	0.22
4,4'-DDE	ND
Endrin	ND
Endosufan II	ND
4,4'-DDD	ND
4,4'-DDT	ND
Methoxychlor	ND
Endrin ketone	ND
alpha-Chlodane	ND
gamma-Chlordane	ND
METALS	**mg/Kg**
Aluminum	911
Antimony	ND
Arsenic	ND
Barium	2.7 J
Chromium	1.8
Cobalt	0.7
Iron	2250
Lead	2.2 J
Magnesium	234
Manganese	30.6
Nickel	1.4
Potassium	86.3 J
Sodium	235 J
Vanadium	3.5
MISCELLANEOUS	**mg/Kg**
TOC	50

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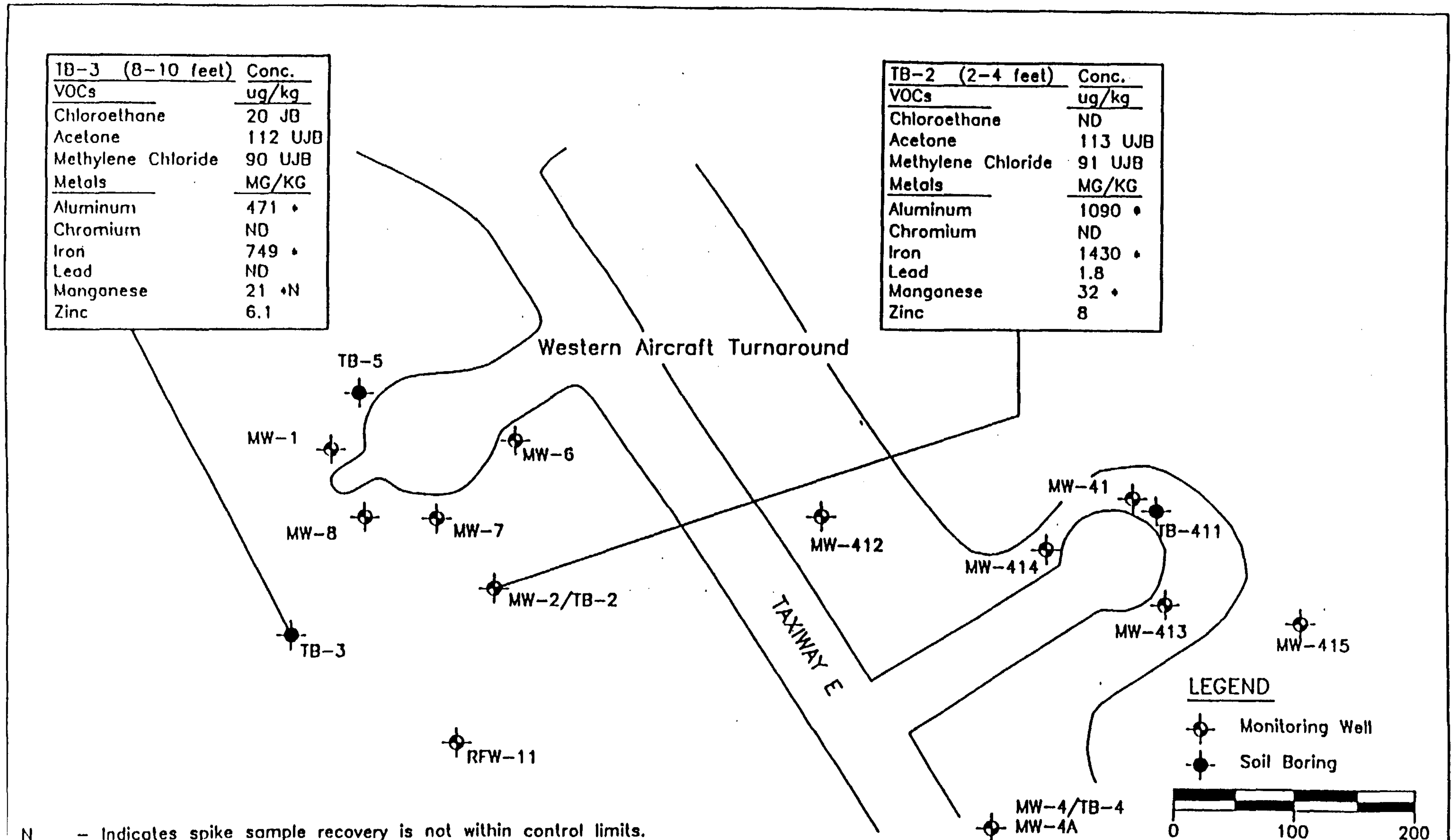
INTERPRETIVE SURFACE SOIL ANALYTICAL RESULTS FOR AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4-1

FS2ARI 10/25/95



N – Indicates spike sample recovery is not within control limits.
ND – Analyzed but not detected.
• – Indicates duplicate analysis is not within control limits.
UJB – Indicates that due to contamination found in the method blank the detection limit has been revised to the value preceding the flag.
J – Indicates an estimated value.
B – Indicates the parameter was present in the associated method blank.

Source: E.C. Jordan 1988, 1990

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INTERPRETIVE SUBSURFACE SOIL (2-10 feet) ANALYTICAL RESULTS AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4-1 A

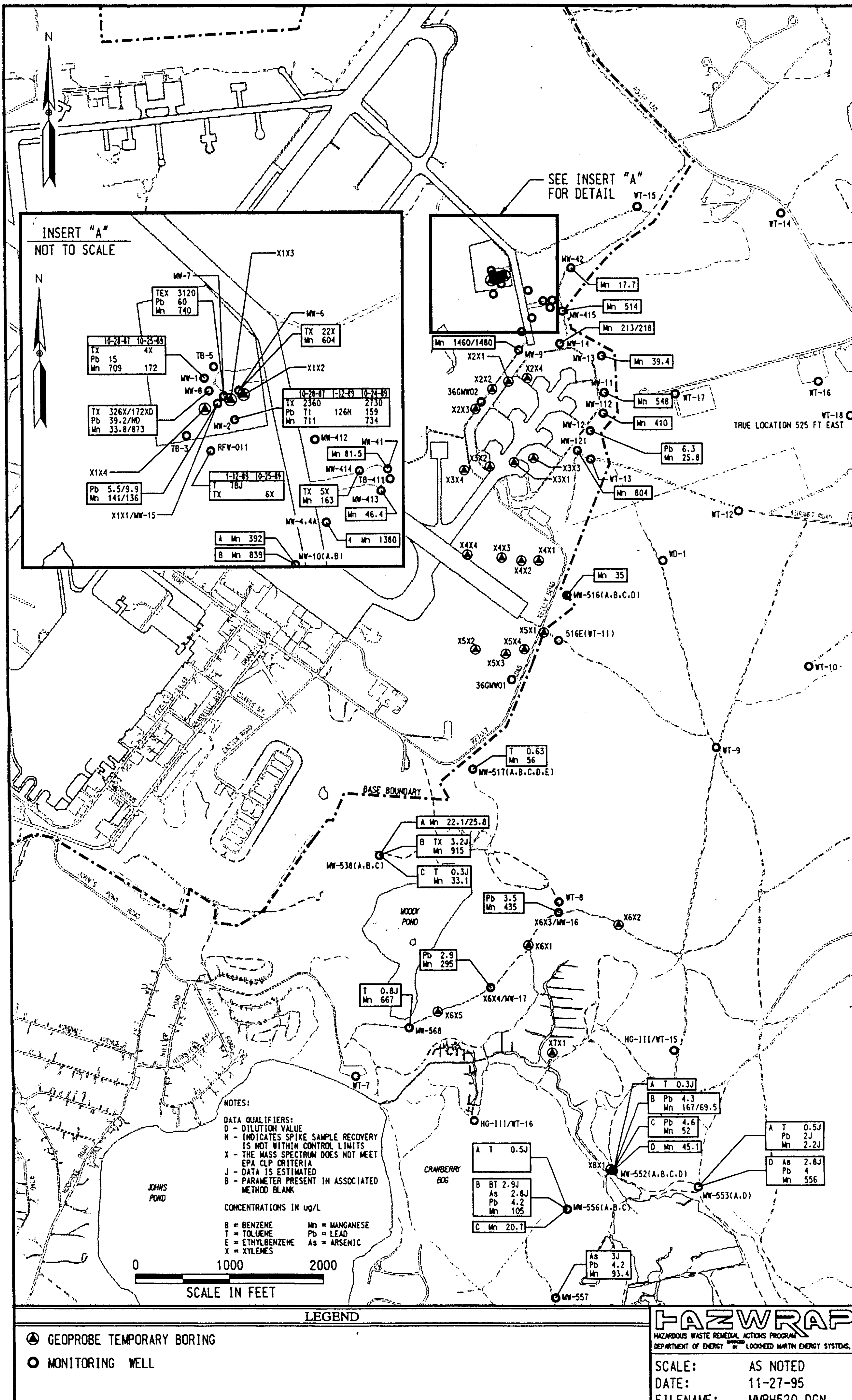
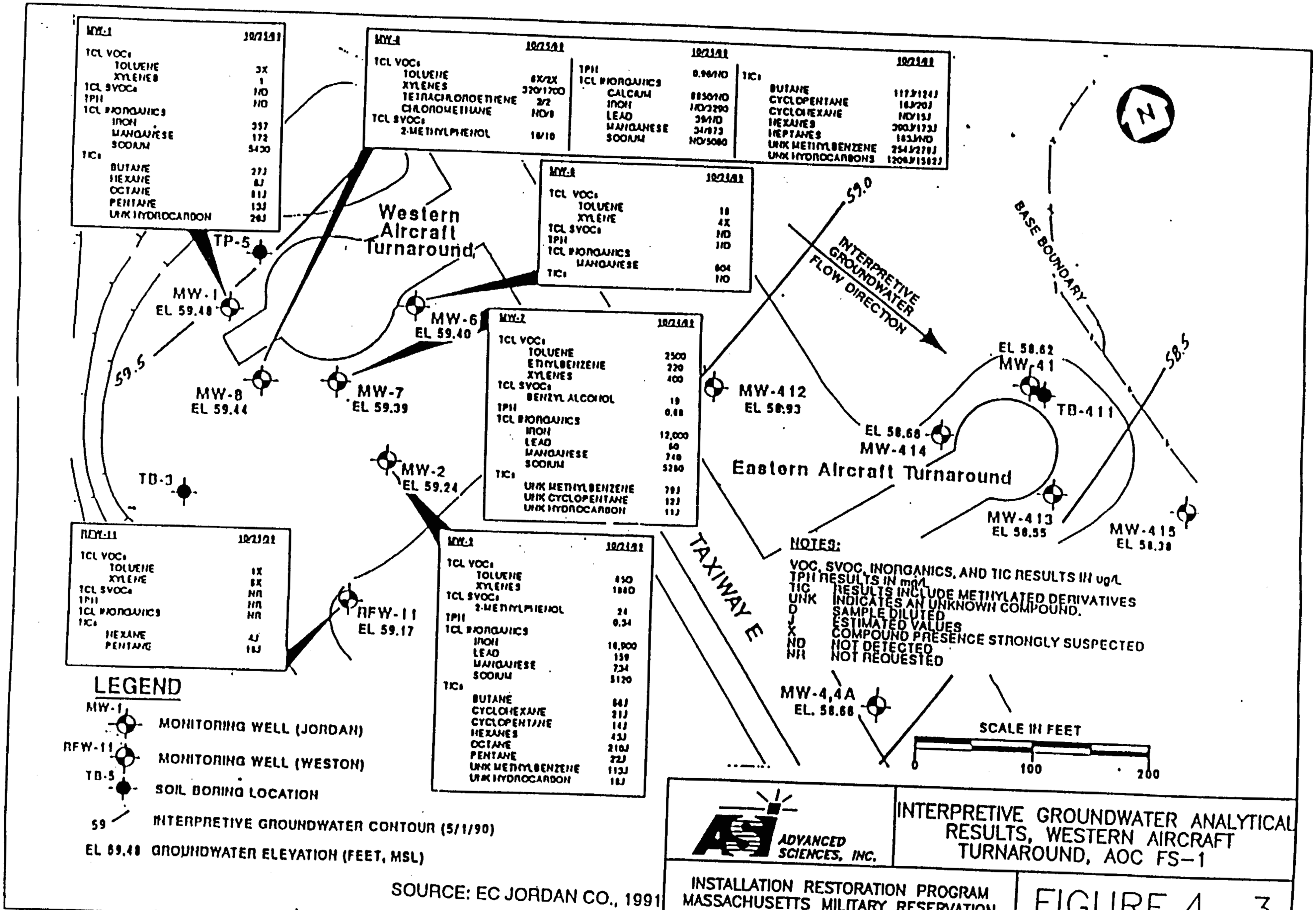


Figure 4-2. Summary of detected concentrations of BTEX, lead, arsenic, and manganese in groundwater prior to 1997/1998.

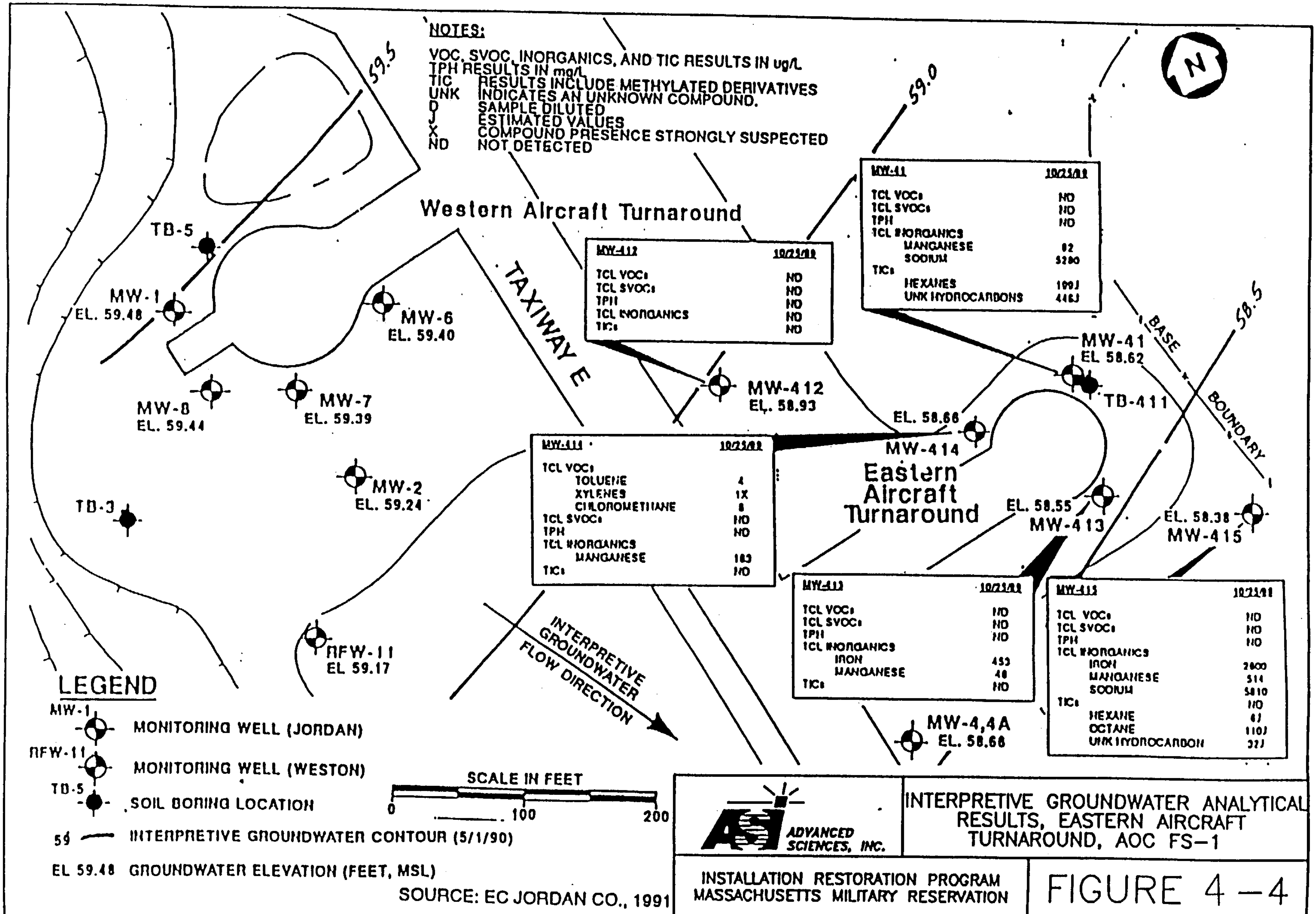


INTERPRETIVE GROUNDWATER ANALYTICAL RESULTS, WESTERN AIRCRAFT TURNAROUND, AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4-3

RI-TEMP 10-23-95



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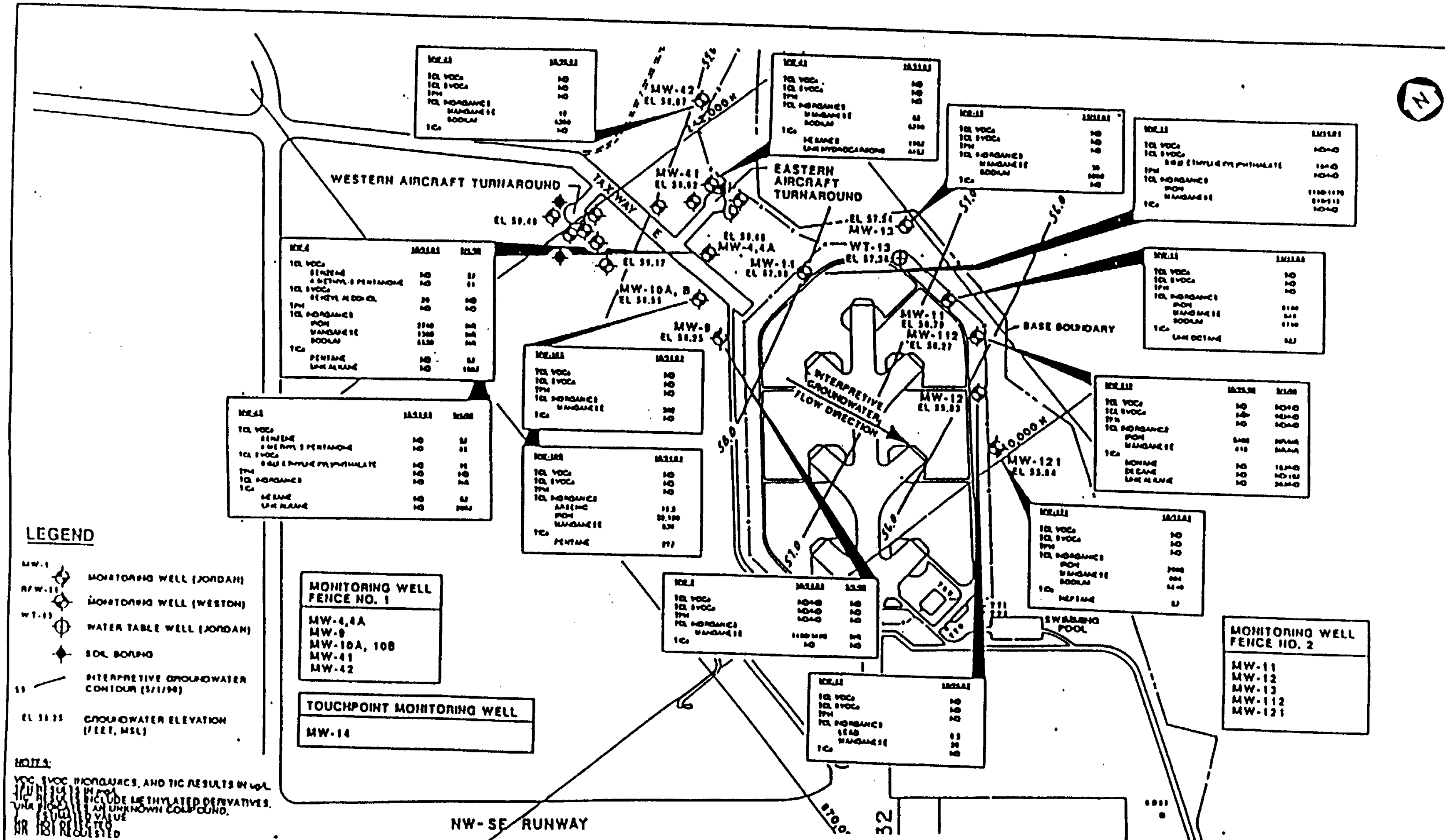
INTERPRETIVE GROUNDWATER ANALYTICAL RESULTS, EASTERN AIRCRAFT TURNAROUND, AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4-4



SOURCE: EC JORDAN CO., 1991

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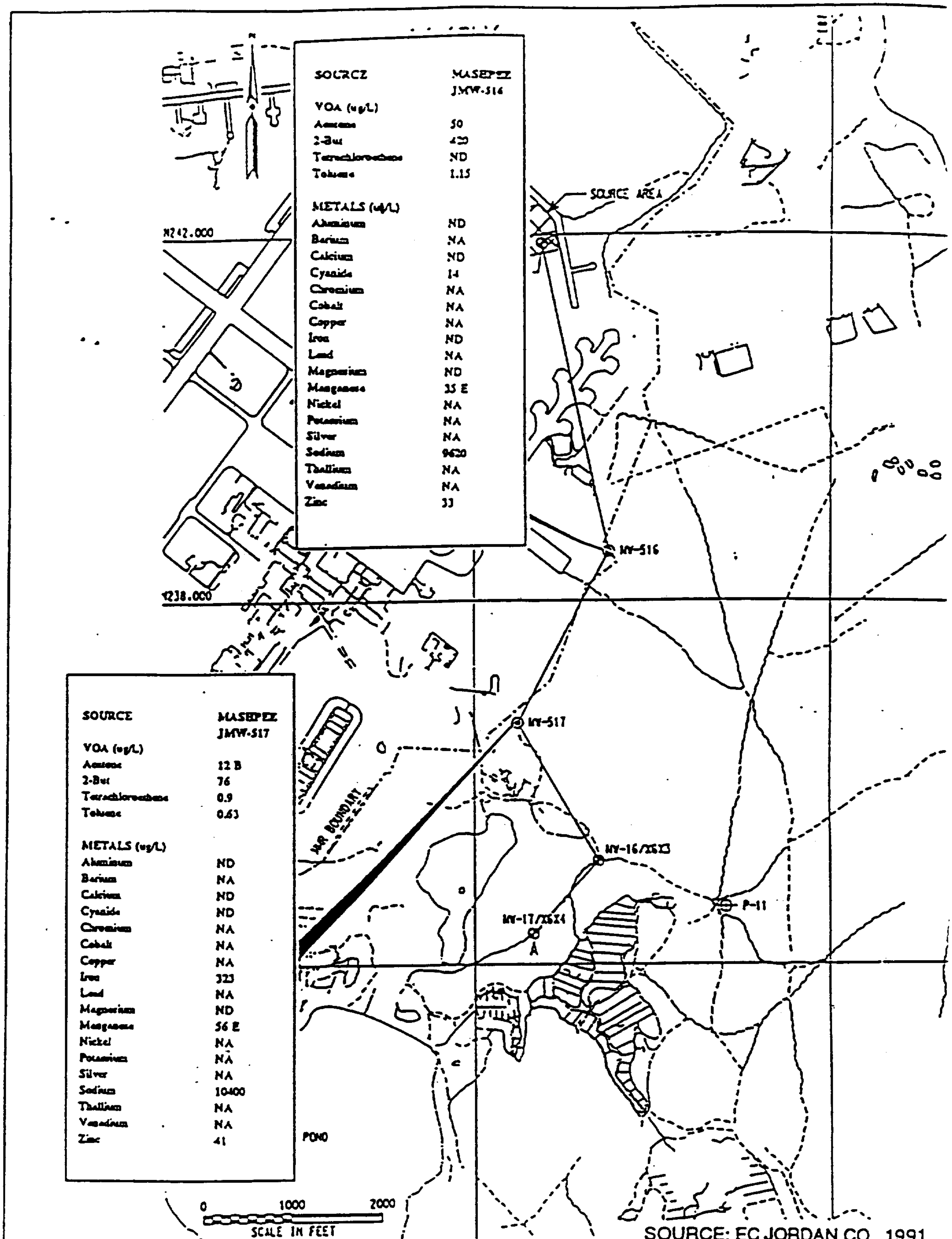
INTERPRETIVE DOWNGRADIENT GROUNDWATER ANALYTICAL RESULTS, AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4 –5



SOURCE	MASHPEE JMW-516
VOA (ug/L)	
Acetone	50
2-But	420
Tetrachloroethene	ND
Toluene	1.15
METALS (ug/L)	
Aluminum	ND
Barium	NA
Calcium	ND
Cyanide	14
Chromium	NA
Cobalt	NA
Copper	NA
Iron	ND
Lead	NA
Magnesium	ND
Manganese	35 E
Nickel	NA
Potassium	NA
Silver	NA
Sodium	9620
Thallium	NA
Vanadium	NA
Zinc	33

SOURCE	MASHPEE JMW-517
VOA (ug/L)	
Acetone	12 B
2-But	76
Tetrachloroethene	0.9
Toluene	0.63
METALS (ug/L)	
Aluminum	ND
Barium	NA
Calcium	ND
Cyanide	ND
Chromium	NA
Cobalt	NA
Copper	NA
Iron	323
Lead	NA
Magnesium	ND
Manganese	56 E
Nickel	NA
Potassium	NA
Silver	NA
Sodium	10400
Thallium	NA
Vanadium	NA
Zinc	41

SOURCE: EC JORDAN CO., 1991

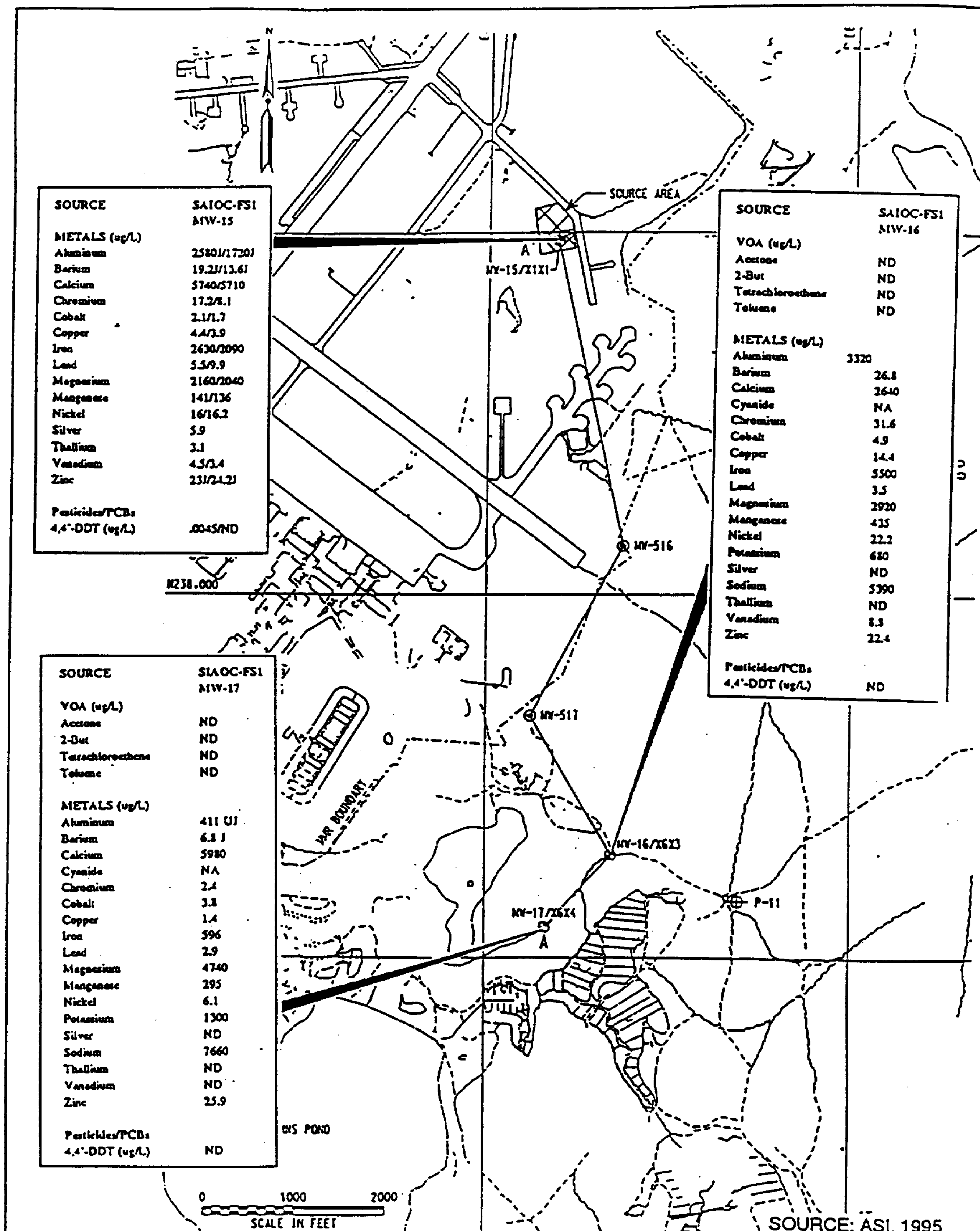
SCREENED AUGER BORING/MONITORING WELL
EXISTING MONITORING WELL
PROPOSED MUNICIPAL PRODUCTION WELL

ADVANCED SCIENCES, INC.

INTERPRETIVE DOWNGRADIENT GROUNDWATER ANALYTICAL RESULTS (MASHPEE STUDY), AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4-6



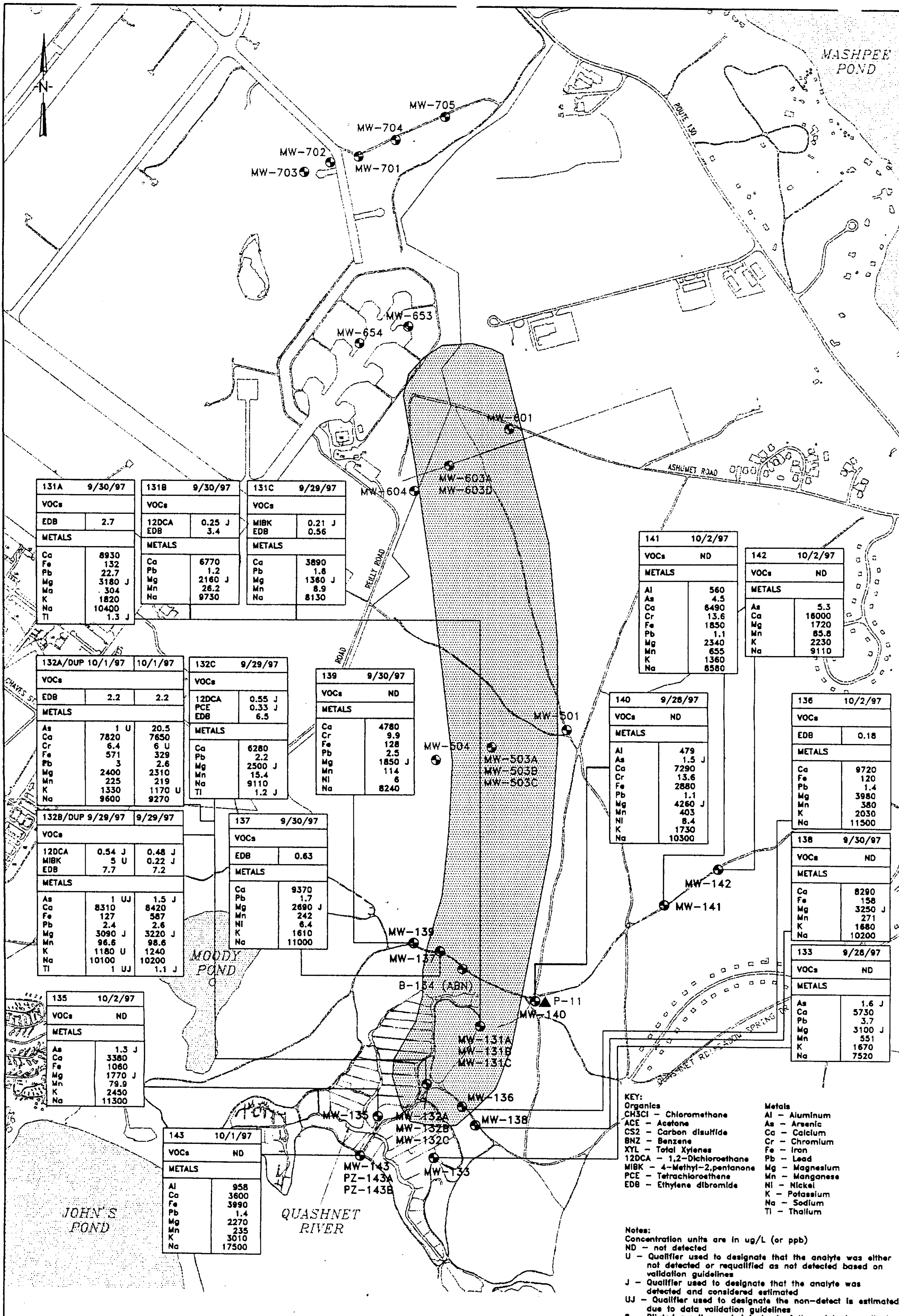
◎ SCREENED AUGER BORING/MONITORING WELL
◉ EXISTING MONITORING WELL
⊖ PROPOSED MUNICIPAL PRODUCTION WELL

ADVANCED SCIENCES, INC.

INTERPRETIVE GROUNDWATER ANALYTICAL RESULTS (1995 DATA), AOC FS-1

INSTALLATION RESTORATION PROGRAM
MASSACHUSETTS MILITARY RESERVATION

FIGURE 4-7



LEGEND

- 1997/1998 MONITORING WELL
- EXISTING PUMP TEST WELL
- APPROXIMATE EDB PLUME

COMMODORE ADVANCED SCIENCES, INC.

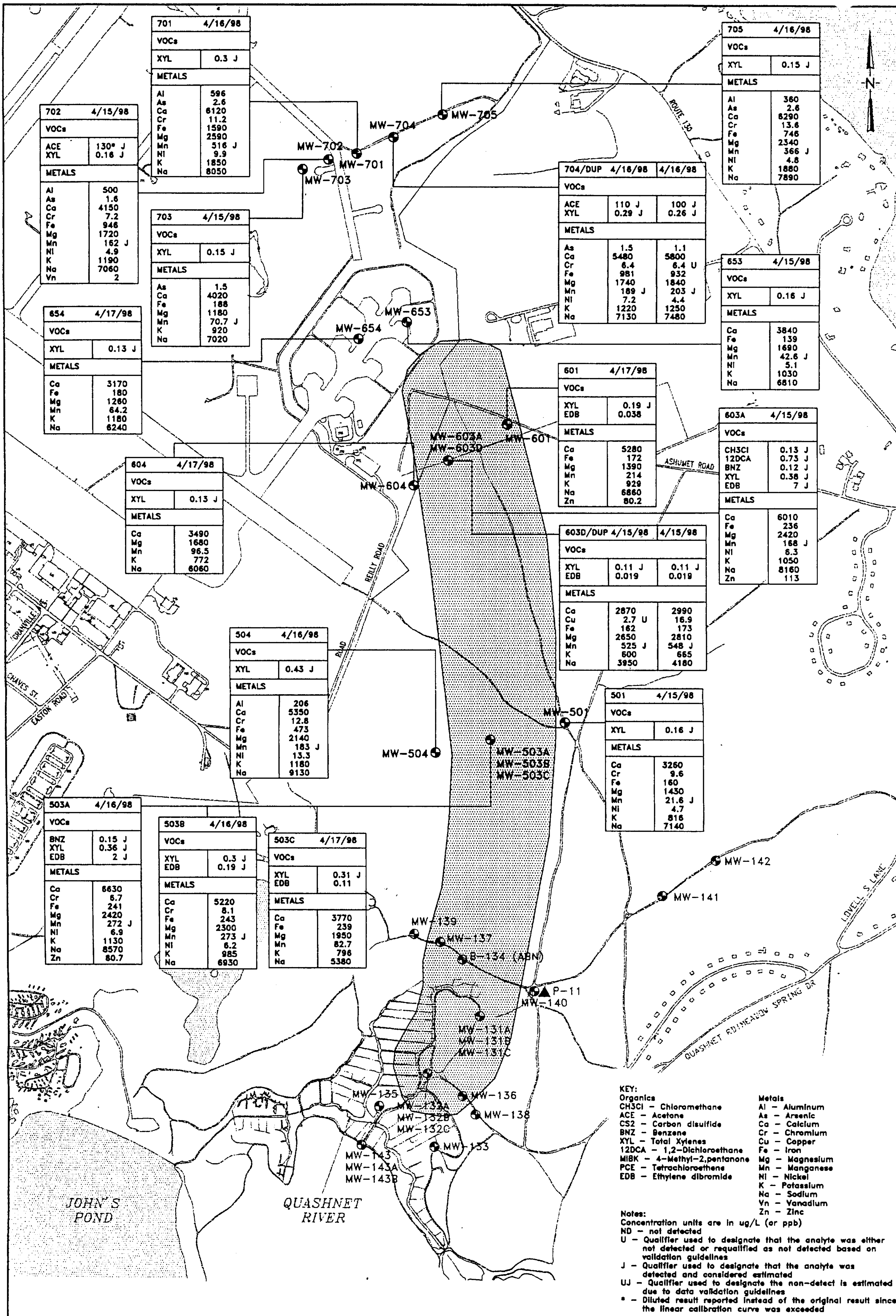
SCALE IN FEET

800 400 0 400 800

FIGURE 4-8
ANALYSIS RESULTS FOR 1997 INSTALLED WELLS

AOC FS-1 Supplemental Remedial Investigation
Massachusetts Military Reservation

SCALE: 1"=800'	DWN BY: KVP
DATE: 2-10-99	FILENAME: MMR97AN.DWG



LEGEND

- 1997/1998 MONITORING WELL
- EXISTNG PUMP TEST WELL
- APPROXIMATE EDB PLUME

COMMODORE ADVANCED SCIENCES, INC.

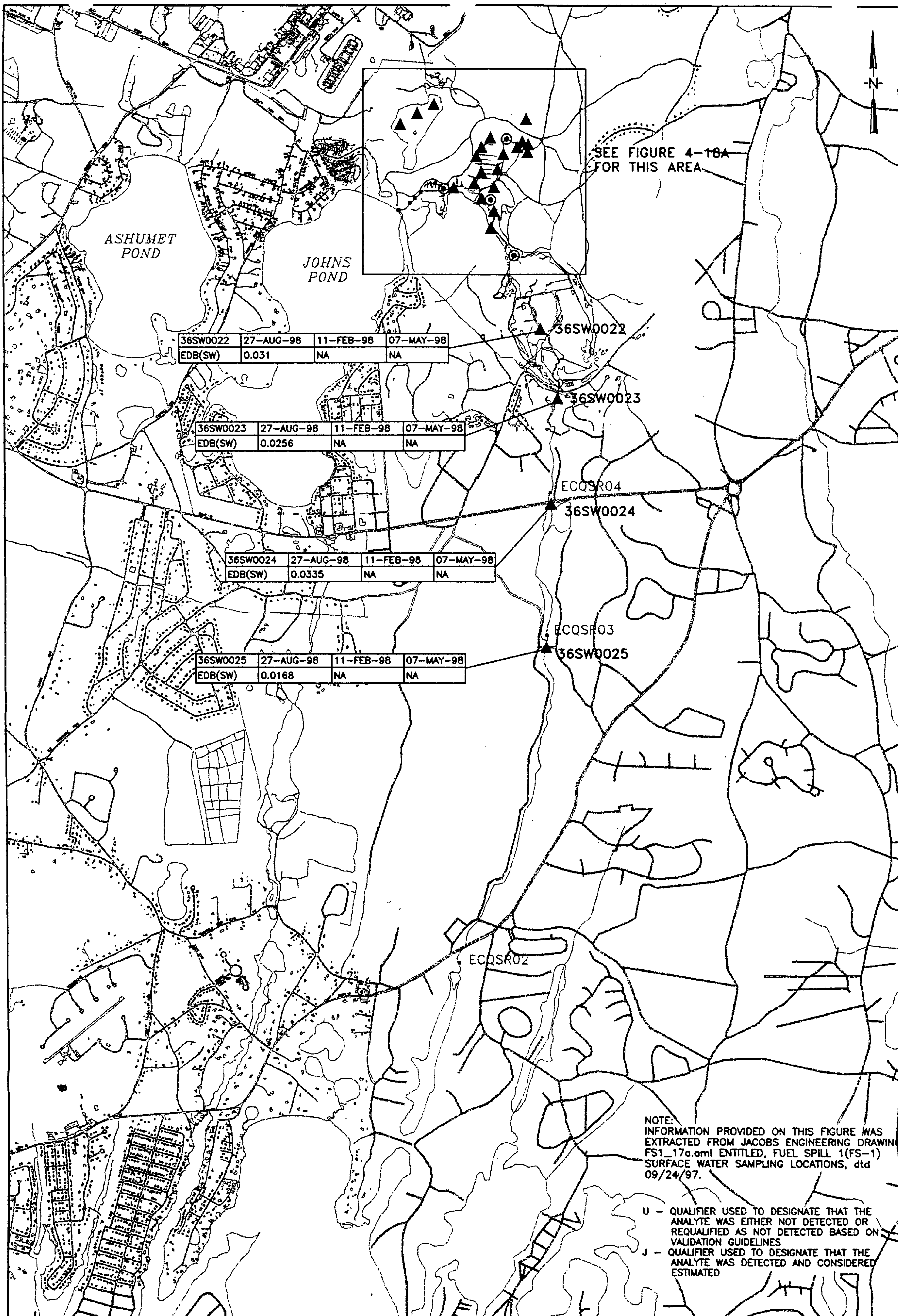
SCALE IN FEET

800 400 0 400 800

FIGURE 4-9
ANALYSIS RESULTS FOR 1998 WELLS

AOC FS-1 Supplemental Remedial Investigation
Massachusetts Military Reservation

SCALE: 1"=800'	DWN BY: KVP
DATE: 2-10-99	FILENAME: MMR98AN.DWG



36SW0022	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.031	NA	NA

36SW0023	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.0256	NA	NA

36SW0024	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.0335	NA	NA

36SW0025	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.0168	NA	NA

NOTE:
INFORMATION PROVIDED ON THIS FIGURE WAS EXTRACTED FROM JACOBS ENGINEERING DRAWING FS1_17a.aml ENTITLED, FUEL SPILL 1(FS-1) SURFACE WATER SAMPLING LOCATIONS, dtd 09/24/97.

U – QUALIFIER USED TO DESIGNATE THAT THE ANALYTE WAS EITHER NOT DETECTED OR REQUALIFIED AS NOT DETECTED BASED ON VALIDATION GUIDELINES

J – QUALIFIER USED TO DESIGNATE THAT THE ANALYTE WAS DETECTED AND CONSIDERED ESTIMATED

LEGEND

- ▲ SURFACE WATER SAMPLING LOCATION
- ◉ SURFACE WATER SAMPLING LOCATION AND DISCHARGE MEASUREMENT POINT
- ▪ ECOLOGICAL STUDY SURFACE WATER SAMPLING LOCATION

ND – NON DETECT
NA – NAT ANALYZED
SED – SEDIMENT (μg/kg)
SW – SURFACE WATER (μg/L)

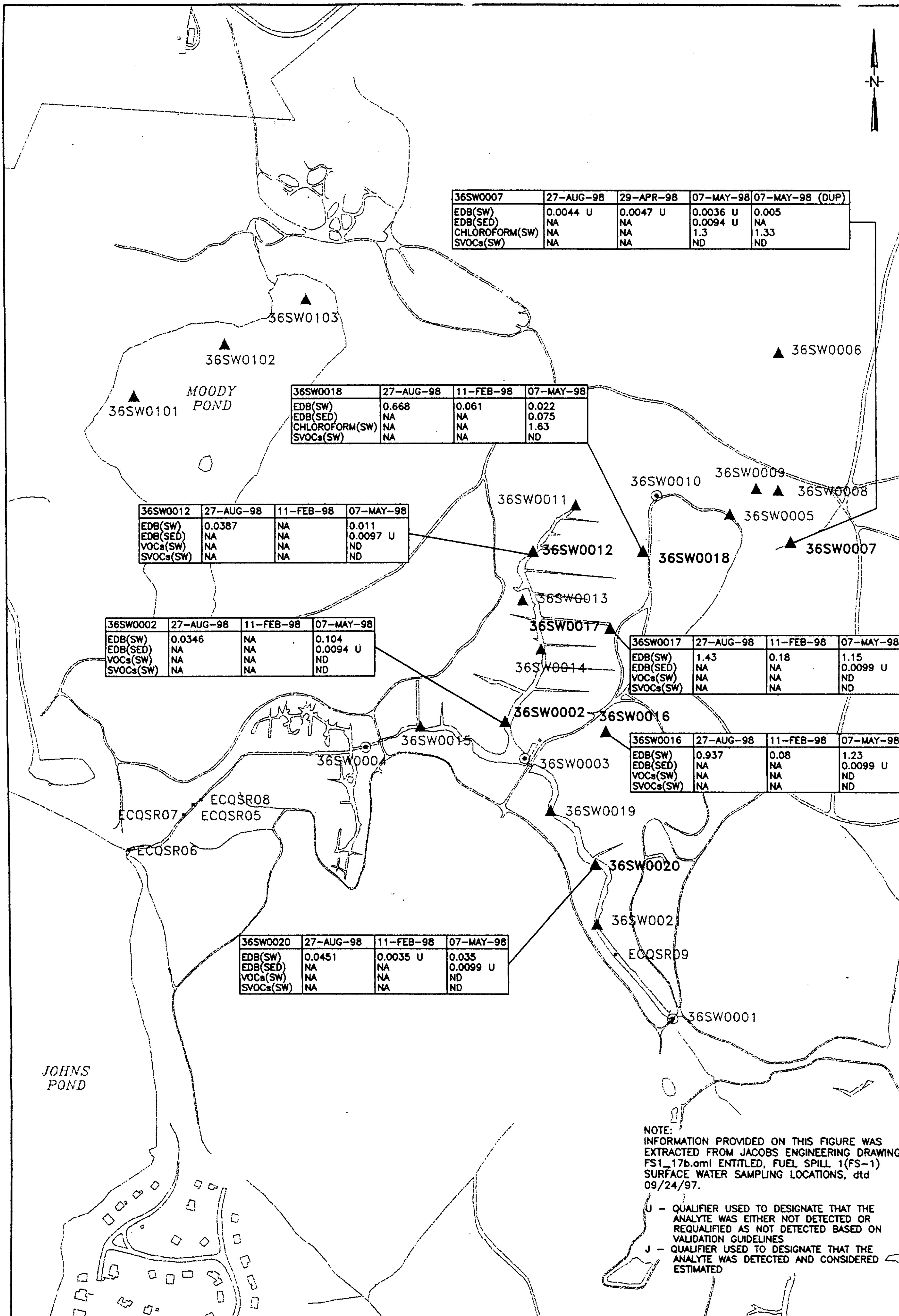
COMMODORE ADVANCED SCIENCES, INC.

SCALE IN FEET
2000 1000 0 1000 2000

FIGURE 4-18
ANALYTICAL RESULTS FOR QUASHNET RIVER SURFACE WATER SAMPLES (EDB)

AOC FS-1 Supplemental Remedial Investigation
Massachusetts Military Reservation

SCALE: 1"=2000'	DWN BY: KVP
DATE: 2-8-99	FILENAME: MMRSWSDA.DWG



36SW0007	27-AUG-98	29-APR-98	07-MAY-98	07-MAY-98 (DUP)
EDB(SW)	0.0044 U	0.0047 U	0.0036 U	0.005
EDB(SED)	NA	NA	0.0094 U	NA
CHLOROFORM(SW)	NA	NA	1.3	1.33
SVOCs(SW)	NA	NA	ND	ND

36SW0018	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.668	0.061	0.022
EDB(SED)	NA	NA	0.075
CHLOROFORM(SW)	NA	NA	1.63
SVOCs(SW)	NA	NA	ND

36SW0012	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.0387	NA	0.011
EDB(SED)	NA	NA	0.0097 U
VOCs(SW)	NA	NA	ND
SVOCs(SW)	NA	NA	ND

36SW0002	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.0346	NA	0.104
EDB(SED)	NA	NA	0.0094 U
VOCs(SW)	NA	NA	ND
SVOCs(SW)	NA	NA	ND

36SW0017	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	1.43	0.18	1.15
EDB(SED)	NA	NA	0.0099 U
VOCs(SW)	NA	NA	ND
SVOCs(SW)	NA	NA	ND

36SW0016	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.937	0.08	1.23
EDB(SED)	NA	NA	0.0099 U
VOCs(SW)	NA	NA	ND
SVOCs(SW)	NA	NA	ND

36SW0020	27-AUG-98	11-FEB-98	07-MAY-98
EDB(SW)	0.0451	0.0035 U	0.035
EDB(SED)	NA	NA	0.0099 U
VOCs(SW)	NA	NA	ND
SVOCs(SW)	NA	NA	ND

NOTE:
INFORMATION PROVIDED ON THIS FIGURE WAS EXTRACTED FROM JACOBS ENGINEERING DRAWING FS1_17b.aml ENTITLED, FUEL SPILL 1(FS-1) SURFACE WATER SAMPLING LOCATIONS, dtd 09/24/97.

U – QUALIFIER USED TO DESIGNATE THAT THE ANALYTE WAS EITHER NOT DETECTED OR REQUALIFIED AS NOT DETECTED BASED ON VALIDATION GUIDELINES

J – QUALIFIER USED TO DESIGNATE THAT THE ANALYTE WAS DETECTED AND CONSIDERED ESTIMATED

LEGEND

- ▲ SURFACE WATER SAMPLING LOCATION
- ◉ SURFACE WATER SAMPLING LOCATION AND DISCHARGE MEASUREMENT POINT
- • ECOLOGICAL STUDY SURFACE WATER SAMPLING LOCATION

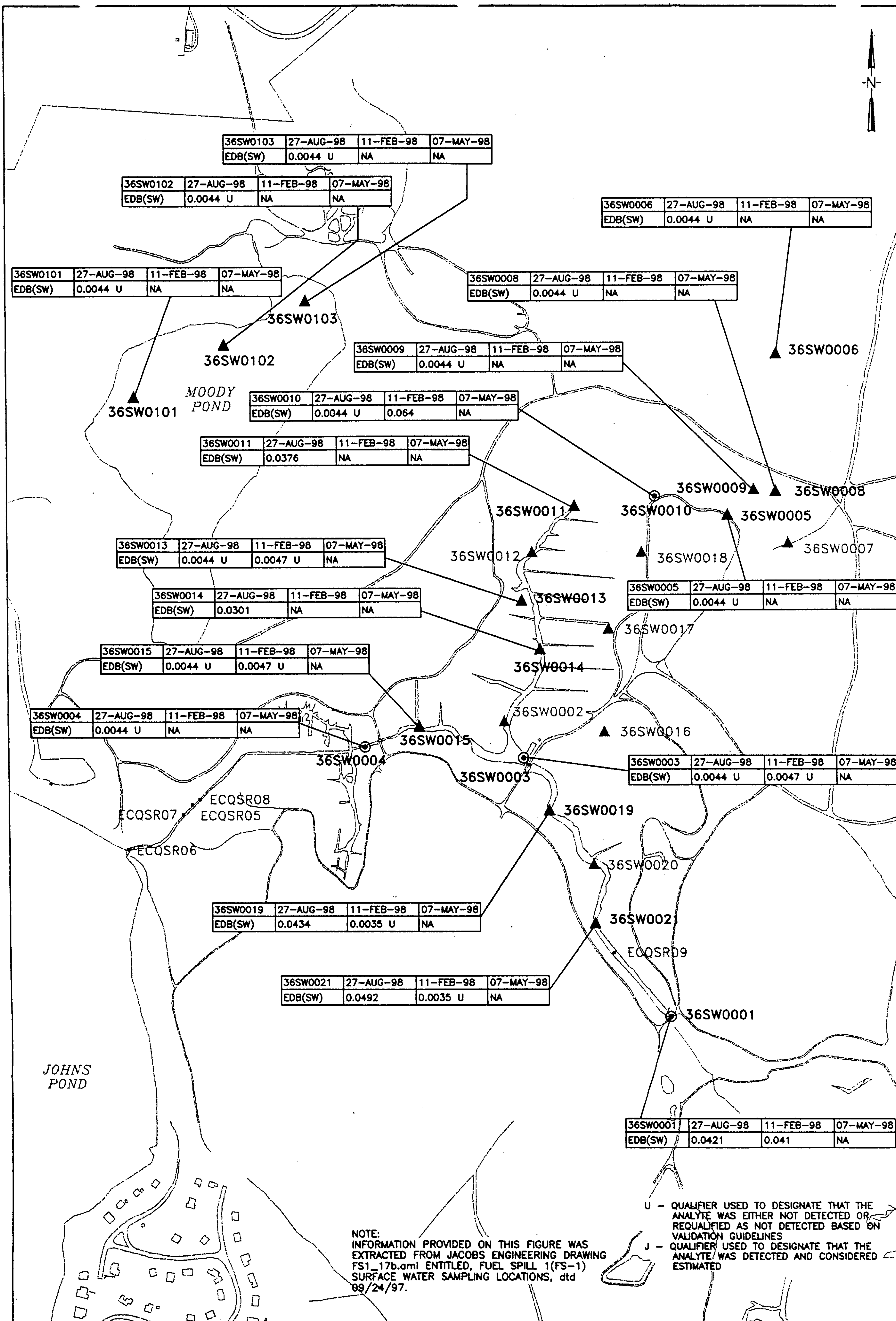
ND – NON DETECT
NA – NAT ANALYZED
SED – SEDIMENT (µg/kg)
SW – SURFACE WATER (µg/L)

COMMODORE ADVANCED SCIENCES, INC.

SCALE IN FEET
400 200 0 200 400

FIGURE 4-18A (SHT 1 OF 2)
ANALYTICAL RESULTS FOR QUASHNET RIVER/ CRANBERRY BOG SURFACE WATER AND SEDIMENT SAMPLES (ORGANICS)
AOC FS-1 Supplemental Remedial Investigation
Massachusetts Military Reservation

SCALE: 1"=400'	DWN BY: KVP
DATE: 2-8-99	FILENAME: MMRSWSDB.DWG



NOTE:
INFORMATION PROVIDED ON THIS FIGURE WAS EXTRACTED FROM JACOBS ENGINEERING DRAWING FS1_17b.aml ENTITLED, FUEL SPILL 1(FS-1) SURFACE WATER SAMPLING LOCATIONS, dtd 09/24/97.

U – QUALIFIER USED TO DESIGNATE THAT THE ANALYTE WAS EITHER NOT DETECTED OR REQUALIFIED AS NOT DETECTED BASED ON VALIDATION GUIDELINES
J – QUALIFIER USED TO DESIGNATE THAT THE ANALYTE WAS DETECTED AND CONSIDERED ESTIMATED

LEGEND
- ▲ SURFACE WATER SAMPLING LOCATION
- ◎ SURFACE WATER SAMPLING LOCATION AND DISCHARGE MEASUREMENT POINT
- • ECOLOGICAL STUDY SURFACE WATER SAMPLING LOCATION

ND – NON DETECT
NA – NAT ANALYZED
SED – SEDIMENT (ug/kg)
SW – SURFACE WATER (ug/L)

COMMODORE ADVANCED SCIENCES, INC.

SCALE IN FEET
400 200 0 200 400

FIGURE 4-18A (SHT 2 OF 2)
ANALYTICAL RESULTS FOR QUASHNET RIVER/ CRANBERRY BOG SURFACE WATER AND SEDIMENT SAMPLES (ORGANICS)

AOC FS-1 Supplemental Remedial Investigation
Massachusetts Military Reservation

SCALE: 1"=400'	DWN BY: KVP
DATE: 2-8-99	FILENAME: MMRSWSDB1.DWG

APPENDIX B
FS-1 1998 GROUNDWATER MODELING RESULTS

JEG-98.06-002
Rev. 2

RESULTS OF THE FS-1 ALTERNATIVES ANALYSIS FOR THE MASSACHUSETTS MILITARY RESERVATION

for

Jacobs Engineering Group, Inc.
Otis Air National Guard Base, Massachusetts

April 8, 1999

RESULTS OF THE FS-1 ALTERNATIVES ANALYSIS FOR THE MASSACHUSETTS MILITARY RESERVATION

by
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Paul M. Craig
and
Dudley J. Benton
of
Advanced Technology Systems, Inc.

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of
Jacobs Engineering Group, Inc.

for

Jacobs Engineering Group, Inc.
Otis Air National Guard Base, Massachusetts

April 8, 1999

File JEG9806002002.DOC

TABLE OF CONTENTS

ACRONYMS

AFCEE	Air Force Center for Environmental Excellence
ATS	Advanced Technology Systems, Inc.
BBM	Buzzards Bay Moraine
CAD	Computer Aided Drafting
cfs	cubic feet per second
ECE	Environmental Consulting Engineers, Inc.
EDB	ethylene di-bromide
FS	Feasibility Study
FS-1	Fuel Spill-1
ft	feet
GB	Gigabytes
gpd	gallons per day
HAZWRAP	Hazardous Waste Remedial Actions Program
JE	Jacobs Engineering Group, Inc.
K	hydraulic conductivity
MB	Megabytes
MCL	Maximum Concentration Level
mgd	million gallons per day
MMR	Massachusetts Military Reservation
MPP	Mashpee Pitted Plain
MSL	mean sea level
RI	Remedial Investigation
RMS	root mean square
SM	Sandwich Moraine
USGS	United States Geological Survey
WAT	Western Aircraft Turnaround
WCC	Western Cape Cod

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This report describes groundwater modeling and analysis of several remedial alternatives for removal and treatment of contaminated groundwater in the Fuel Spill - 1 (FS-1) Plume at the Massachusetts Military Reservation (MMR), which is located on Western Cape Cod (WCC). This work was conducted during late 1998 and early 1999 in support of the FS-1 Feasibility Study (FS) being conducted by the Hazardous Waste Remedial Action Program (HAZWRAP), in Oak Ridge, Tennessee and the Bog Separation Initiative being conducted by Jacobs Engineering Group, Inc. (JE) located at Otis Air Force Base.

1.1 FS-1 Modeling History

This report is intended to summarize and present all of the groundwater modeling results obtained by Advanced Technology Systems, Inc. (ATS) for the FS-1 site. A total of three separate modeling efforts associated with the FS-1 remediation design have been conducted by ATS from September 1998 to February 1999. The Stage 1 simulations investigated remediation of the entire plume through the use of an in-plume action, such as an axial well fence. The Stage 2 simulations focused on remediation of the areas immediately upgradient and adjacent to the K-1 Bog. Stage 3 simulations combined the systems modeled in Stages 1 and 2.

Groundwater modeling was used to evaluate the effectiveness of various remedial alternative scenarios for extracting, treating, and reinjecting ethylene di-bromide (EDB) contaminated groundwater from the FS-1 plume. The modeling work was conducted in three stages. The first stage investigated in-plume extraction and reinjection system designs for the first draft of the FS-1 FS (HAZWRAP, 1998). The second stage investigated a focused remedial alternative for the bog, which included a single deep extraction well coupled with shallow well points for extraction and injection. The third stage combined and expanded the remedial alternative for the bog and included evaluation of an in-plume axial extraction fence.

The data that went into the first stage of the modeling was from the recently completed HAZWRAP Remedial Investigation (RI) (HAZWRAP, 1998) and the existing "approved" JE regional model. Each of the two subsequent stages used additional field data supplied by JE during the modeling efforts.

1.2 Objective

The objective of this study was to use ATS's existing understanding of the hydrogeologic system to develop a targeted set of alternatives to efficiently remove EDB from the FS-1 plume and protect the Quashnet Bog. For each alternative tested, the system effectiveness was quantified as EDB mass removal over time. The objective of the groundwater modeling activities was to identify the remedial alternative that provided the most effective contaminant mass removal. By this definition, the alternative that removed the most mass in the shortest time was identified as the most efficient system. Protecting other bogs from unintended and/or negative effects developed by the remedial alternative were not explicitly evaluated. Evaluating the effects of the selected remedial alternative on other area bogs was not within the scope of this effort.

The cost to design and install the system was not included in this modeling analysis. Estimated costs of the selected remedial alternative will be provided in the feasibility study.

1.3 Scope

The scope of work included:

Development of a Three Dimensional Contaminant Plume. The concentration data taken at various depths in the sampling wells within the plume area as well as the outline of the extent of the EDB plume in plan view were used to develop a numerical representation of the plume and a corresponding particle seed file used in the particle tracking program.

Development of a 3-D Groundwater Model. A 3-D groundwater flow model capable of accurately simulating the advective processes governing movement of the plume was developed. This model was developed to compute flow and head within the model domain based on the geohydrological properties, recharge, water table elevation, and pumping scenarios. Groundwater and surface water interactions are not explicitly incorporated in the model.

Analysis of Alternative Remediation Strategies - Stage 1. The 3-D groundwater model was used first to compute the ambient, or no-action, flow field. The particle tracking program was then used to determine the plume movement. Based on these results, six in-plume alternatives were tested. Three well placement configurations and pump operations were initially developed. The particle tracking results from these three scenarios were then used to develop three refined scenarios. The most efficient of these six scenarios was identified as the most desirable of the in-plume pump and treat remediation strategies.

Analysis of Alternative Remediation Strategies - Stage 2. Three additional scenarios were simulated which included a focused remedial system for the bog. This system included a series of shallow well points that either extracted or injected water near the bog. The treated water was simulated as either being reinjected directly to the groundwater system or placed into the streams that drain from the bog. Water that was discharged into the streams is not explicitly included in these models since groundwater and surface water hydraulics are not coupled in this modeling approach. However, the volume of water discharged to the surface would not likely cause a higher level of water in the bog since they already are receiving that water. Therefore, it was assumed that the water that was replaced to the stream did not impact the performance of the extraction system. The alternatives simulated during this stage of work were provided to ATS by JE and were designed to be compatible with the ongoing K-1 Bog Separation Project

Analysis of the Combined Alternative Remediation Strategies - Stage 3. Three additional scenarios were simulated which included the focused remedial system for the bog, the bog system plus an axial extraction fence, and the bog system with the axial fence and lateral reinjection. These simulations determined the combined effect of using both types of remediation systems.

Summary Modeling Report. Prepared a report summarizing the model development and alternatives analysis of Stage 3 results.

1.4 Report Organization

Section 2 of this report contains a brief introduction to MMR, including site history information, details about the FS-1 site, and a general discussion of the hydrogeologic setting. The FS-1 site conceptual model is also covered in detail. Section 3 contains information on the model development including code selection, model assumptions, and details of the how various aspects of the hydrogeologic system are modeled. Specific discussions are provided for hydraulic conductivity distribution, the

method for simulating ponds, streams and rivers, the selection of model boundaries, and analysis of the 3-D contaminant concentration field. Section 4 briefly discusses the model calibration as conducted in Stage 1 of this work. Section 5 presents the model results from Stages 1, 2 and 3. Section 6 provides the conclusions of the study and presents recommendations for future work.

2. BACKGROUND

2.1 MMR Site Location and Description

MMR encompasses approximately 22,000 acres on Western Cape Cod, Massachusetts, about 60 miles south of Boston (Figure 1). It is located in Barnstable County, in the towns ofBourne, Falmouth, Mashpee, and Sandwich. The military reservation currently houses various facilities and related operations of the following Department of Defense branches: U.S. Coast Guard, U.S. Marine Corps Reserve, U.S. Army National Guard (Camp Edwards), U.S. Air Force, and U.S. Air National Guard (Otis Air National Guard Base). The Veterans Administration National Cemetery, the U.S. Department of Agriculture, and the Commonwealth of Massachusetts also use MMR property. Most active facilities are in the southern portion of the reservation. The northern portion consists of several firing ranges, which have been used for training with live ammunition.

2.2 MMR History

Since its establishment in 1911, a variety of activities have been conducted on MMR, including troop training and deployment; fire-fighting training; ordnance development, testing and training; aircraft and vehicle operation and maintenance; and fuels transport and storage. Most activities can be associated with either mechanized army training, maneuvers and associated functions, or with military aircraft operations, maintenance, support, and associated functions. Operations on the military reservation intensified during and just after World War II (1940 to 1946). From 1955 to 1970, a substantial number of surveillance and air defense aircraft operated out of the Air National Guard portion. Since that time, fewer aircraft have been active at MMR; one reserve fighter squadron now trains at the airfield.

2.3 FS-1 Background

The FS-1 plume originates in an area near the Western Aircraft Turnaround (WAT) site, which is located adjacent to Taxiway E (Figure 2). Base records indicate that between 1955 and 1970, military activities in this area included the testing of various fuel management practices. For example, fuel dump valves were tested on various types of aircraft. Although it is not accurately known how much fuel was released during the exercises, it is believed that uncontained fuel entered the ground and has caused the FS-1 plume. Since that time, the FS-1 plume has developed to the south along a slightly arching path. The fuel constituents, which include volatile organic compounds and inorganic compounds, currently discharge to the Quashnet River and its tributaries around a bog, which is located about 2000 ft northeast of the northeast corner of Johns Pond (Figure 2).

The Remedial Investigation (RI) Report for the FS-1 Plume (HAZWRAP, 1998) concluded that there was a cancer risk due to EDB, albeit a very small one, to individuals that consume groundwater from within the FS-1 plume. As a result, the Air Force Center for Environmental Excellence (AFCEE) has contracted HAZWRAP to complete an FS to determine ways of reducing the health risks arising from groundwater consumption.

The location of the FS-1 plume with respect to WCC and the groundwater model is shown in Figure 1. The plume is approximately 6950 ft long and 600 to 1200 ft wide, and ranges in thickness from 50 to 150 ft. The maximum plume thickness occurs in the bog as the plume rises from deep within the aquifer to its discharge point. The bog in this area represents the discharge point for the FS-1 plume.

The significant hydrologic features of the FS-1 area are the Mashpee Pond on the northeast, the Mashpee River on the east boundary, Johns Pond to the southwest, and a bog adjacent to Johns Pond (K-2 Bog), which drains into the Quashnet River. For purposes of discussion in this report, this bog will hereafter be referred to as the Quashnet Bog. These major hydrological features are shown in Figure 3.

2.4 FS-1 Geology and Hydrogeology

A number of studies of the geology of Cape Cod have been produced. Two noteworthy publications are *A Geologist's View of Cape Cod* (Strahler, 1966) and *Cape Cod and the Islands: the Geologic Story* (Oldale, 1992). The United States Geological Survey (USGS) has recently summarized the lithostratigraphic-chronostratigraphic model of WCC in their publication "Use of Particle Tracking to Improve Numerical Model Calibration and to Analyze Ground-water Flow and Contaminant Migration, Massachusetts Military Reservation, Western Cape Cod, Massachusetts" (Masterson et al., 1996). From these studies, much has been learned about the glacial history of the area.

The geology of WCC comprises glacial sediments deposited during the retreat of the Wisconsin stage of glaciation, between 7,000 and 15,000 years ago. The regional geology consists mainly of three extensive sedimentary units: the Buzzards Bay Moraine (BBM), the Sandwich Moraine (SM), and the Mashpee Pitted Plain (MPP). The BBM and the SM lie along the western and northern edges of WCC, respectively. The MPP, which consists of well to poorly sorted, fine- to coarse-grained sands forming a broad outwash plain, lies between the two moraines.

The FS-1 plume is located within the MPP. The sediments comprising the MPP in the main body of FS-1 groundwater plume are primarily composed of fine- to coarse-grained sands. As the plume reaches the Quashnet bog area, more laterally and vertically discontinuous fine-grained units (peat, clays, and very fine-grained sands and silts) are encountered. Within the bog itself, peat thickness of up to 30 ft have been documented. The region around the bog is generally more lithologically heterogeneous than other parts of the MPP. As new wells are drilled in the area, the lithologic control improves and a better understanding of the local-scale lithologic distribution is achieved. It appears that as new data is collected, the lateral extents of some of the silt and clay units are expanding.

The base of the active groundwater flow system in this area is defined by a basal silt/clay unit that lies on top of bedrock. The elevation of this unit ranges from about -140 to -160 ft mean sea level (msl). The actual bedrock elevation in the FS-1 discharge area is not shown on the available geologic cross-sections (HAZWRAP, 1998) because drilling generally cannot penetrate the basal unit. The total thickness of saturated, permeable sediments above the basal unit is approximately 180 to 190 ft in the FS-1 discharge area.

2.5 Conceptual Model

2.5.1 Groundwater

For a numerical groundwater model to predict aquifer responses and other hydrologic impacts from the plume containment activities, the model must be based on the conceptual understanding of groundwater advective flow. To understand details of the FS-1 plume trajectory, it is necessary to understand both the large-scale and local-scale aspects of flow in the WCC aquifer.

On a large scale, the conceptual groundwater flow model for the WCC aquifer is relatively simple. It is a radial groundwater flow system in a single, unconfined aquifer. The center of the radial flow system is near the FS-12 site (Camp Good News). This area consistently has the highest groundwater elevations. The water table can fluctuate between 3 and 10 ft annually. Generally the water table is highest in the spring and lowest in the fall. In March 1993, the groundwater elevations at the center of the mound were measured at approximately 70 ft above msl. From here, the groundwater moves radially toward Cape Cod Bay to the north, Buzzard's Bay to the west, and Nantucket Sound to the south. Groundwater also flows to the south and east within the MPP. As the groundwater approaches the

shorelines of the Western Cape, the elevation of the water table approaches msl. Fresh water is found vertically beneath the groundwater mound. Seawater can be found below the land surface along certain portions of the shoreline. However, most of the WCC aquifer is fresh water.

Near the groundwater mound, a greater percentage of recharge entering the aquifer tends to move more vertically than horizontally. This tends to cause any potential groundwater contaminants near the mound to move vertically downward. As water flows away from the mound, groundwater flow paths become more horizontal. As groundwater approaches an inland discharge point such as a bog, pond or stream, it rapidly moves upward as it discharges. This describes the flow path taken by the FS-1 plume.

The source of the FS-1 plume was ground-surface, uncontained fuel releases. As the fuel entered the ground, it was driven downward by recharge accretion. The plume continued to dive along its southernly flow path until it encountered the basal silts and clays. Once this interface was reached, the plume continued to move horizontally along the silt/clay boundary. The silt and clays have hydraulic conductivities at least five times lower than the overlying MPP outwash sediments, thus restricting flow to the outwash sediments (ABB-ES, 1994). Therefore, the bottom of the plume was bounded by the silt/clay interface and the flow direction was set based on the regional hydraulic gradient.

As the plume reached the zone of hydraulic influence of the bog, the horizontal flow direction changed from southerly to southwesterly. This flow direction change occurred because the bog is a natural groundwater discharge area. Not only did the horizontal flow direction change, the flow changed from horizontal to vertical. The rapid upward movement of water into the bog has been determined by chemical profiling of the entire saturated thickness of the aquifer both upgradient and downgradient of the bog (HAZWRAP, 1998). This work has determined that the entire saturated thickness of groundwater that contains the FS-1 plume discharges to the bog. The FS-1 plume moves rapidly upwards and completely discharges to the bog. The upward movement of the FS-1 plume is based on data collected during the RI (HAZWRAP, 1998) and subsequent investigations. This is a very important aspect of this conceptual model and is a critical assumption used in the design of the remediation system for the FS-1 plume.

Since the plume discharges completely to the Quashnet Bog, other hydrological features such as ponds and streams do not substantially impact the FS-1 plume. Once the plume discharges to the bog, it exits the groundwater system and becomes a part of the Quashnet River system. Therefore, to complete the conceptual model, it is important to understand the relationship between the Quashnet bog and the Quashnet River system.

2.5.2 Groundwater/Surface Water Interaction

2.5.2.1 Quashnet Bog

Most of the inland bogs on the Cape are derived from shallow ponds that have filled with organic material. Generally, this organic matter has consolidated and degraded to peat. The peat acts as a low hydraulic conductivity (K) unit relative to the higher K sands that underlie the peat. The peat inhibits groundwater discharge in the central area of the bog and forces the groundwater to discharge along the perimeter of the bog where the peat thickness is less. This implies that the peat thickness and distribution controls, to a large degree, where groundwater flows into the bog. Therefore, any remediation system developed for the bog situation must take into account the details of the peat distribution. Upon exiting the groundwater system, the water flows above ground through the bog, ultimately leading to the Quashnet River.

2.5.2.2 Quashnet River

Water that flows out of a discharge structure from Johns Pond is the headwater of the Quashnet River. Within 1000 ft from this point, a significant amount of additional water is added to the Quashnet River from groundwater discharge that occurs in the bogs. Measurements made in 1997 and 1998 indicate that the bogs receive between 4.3 and 5.9 cubic feet per second (cfs) of groundwater discharge,

which is 2.7 to 3.8 million gallons per day (mgd) (Jacobs Engineering, 1999). This water flows to the south, away from the bogs via the Quashnet River and eventually reaches the ocean.

The relationship between groundwater discharge and flow in the Quashnet River has now been quantified. With nearly 3 mgd of groundwater discharge feeding the Quashnet River on a daily basis, it is clear to see that the bogs are a regional groundwater discharge point. This is the reason that the FS-1 plume completely discharges to the Quashnet bogs.

3. MODEL DEVELOPMENT

The numerical model developed for FS-1 remedial alternative analysis was based on the most updated regional model for WCC (Jacobs Engineering, 1998). The FS-1 model contains the same hydraulic conductivity distributions used in the regional model with additional silt and peat layers included in the bog areas. The saturated flow model is built from the water table down to bedrock. The model boundaries and boundary conditions were selected based on natural hydraulic boundaries of the regional flow system. The total surface area of this model is 6.18 square miles. The model spans approximately 12,840 ft in the east-west direction, 15,225 ft in the north-south direction, and varies in thickness. The thickness increases from about 200 ft in the FS-1 plume area to over 370 ft in the south part of the model, where depth to bedrock is greater.

3.1 Numerical Modeling Code Selection

3.1.1 Required Code Capabilities

Any model developed to test an MMR remedial alternative design must accurately simulate numerous features of the groundwater system. Numerical model capabilities must include simulation of:

- 3D flow in a heterogeneous, anisotropic aquifer;
- interaction of groundwater and surface water bodies including streams and ponds;
- irregular boundaries in both plan-view and vertical section;
- groundwater using either finite-difference or finite-element methods;
- multiple pumping and injection wells with the proper numerical treatment of flow in heterogeneous porous media;
- saturated or a combination of saturated and unsaturated conditions;
- steady-state and transient flow conditions; and
- transport of non-reactive contaminants.

In addition to these features, the code selected must be verified, documented and be numerically and memory efficient. The model input must be relatively straightforward to allow for timely creation or modification. Finally, the numerical output must be amenable to rapid graphical post processing and analysis.

3.1.2 Groundwater Flow Code Selection

The model code selection criteria used by ATS focused on the numerical capabilities of each code and how well each code could represent the physical system. During evaluation of possible flow codes, the criteria were weighted according to their importance to the design of well networks for efficient plume capture. The primary criteria considered were based on the groundwater modeling objectives for the FS-1 plume, which focused on plume containment in the bog area and an axial well fence.

The primary code selection criterion was the capability to accurately simulate pumping and injection wells in a heterogeneous, anisotropic aquifer that had numerous connections to large ponds, bogs and streams. This capability was considered essential because of the large areas covered by ponds and streams and because the K-field changed significantly with depth across most of the aquifer. A secondary selection criterion was the flow code's capability to simulate unsaturated flow processes because unsaturated simulations may be necessary in the future at the FS-1 site. Additional code selection criteria included the capability to implement finite elements. A finite-element option provides greater flexibility than finite differences to represent irregular boundaries and can be locally refined in regions where large hydraulic gradients exist near the pumping wells, especially in the bog area.

During the code selection, a determination was made on the anticipated modeling approach based on estimates of model size needed to achieve the initial objectives. This determination specified that although a very thick unconfined aquifer exists, it was most likely that saturated flow simulations would be used for the design for at least two reasons. First, it was reasoned that the relatively small changes in the saturated thickness of this aquifer caused by pumping would be small enough such that error associated with using a confined flow model (saturated flow only) would be small. Essentially, errors associated with using a saturated flow model are minor compared to other uncertainties (K-field, boundary conditions, porosity, etc.). Second, it was estimated that the computer memory requirements and run times for a variably saturated flow model would be prohibitive due to vertical discretization requirements in the unsaturated zone. Numerous groundwater flow models were initially investigated. Using the above criteria, the FRAC3DVS computer model was selected because:

- The code has robust algorithms that represent numerous groundwater processes according to first principles.
- The code has been successfully used by ATS in conjunction with particle-tracking/random-walk codes to simulate groundwater transport and to design both the FS-12 and SD-5 groundwater collection systems at MMR.

A third important point regarding the selection of FRAC3DVS is ATS's suite of preprocessors, postprocessors, particle-tracking, and random-walk codes that accelerate and compliment the application of FRAC3DVS at MMR.

3.1.3 Particle Tracking Code Selection

Several widely used particle-tracking codes are available, including MOC (Konikow and Bredeheoft, 1978), RANDOM WALK (Prickett et al., 1981), PATH3D (Zheng, 1992b), MODPATH (Pollock, 1989), and MT3D (Zheng, 1992a). Factors that affect the application of these models include hydrodynamic dispersion capabilities and the numerical method used to track the particles. The codes MODPATH and PATH3D cannot simulate hydrodynamic dispersion. These codes calculate only flow paths and are primarily useful for delineating well capture zones. These particle tracking codes have the advantage over finite-difference and finite-element codes of avoiding numerical error when the grid spacings are much larger than the characteristic dispersion length of the system. Particle-tracking codes such as MOC and RANDOM WALK have solution techniques that prevent numerical errors from occurring regardless of the ratio of grid spacing to dispersion length. This capability is a significant benefit because dispersion length in the vertical transverse direction typically ranges from 0.0033-0.3 ft. Such element lengths are too small for practical numerical model applications.

A limitation of MOC and RANDOM WALK is that they are two dimensional (2D). MT3D is a 3D particle-tracking code, but it also has limitations. Because of its mathematical coding, MT3D is not designed for applications with grid meshes other than layers of rectangular blocks. MT3D was specifically designed to be coupled with the groundwater flow model MODFLOW (McDonald and Harbaugh, 1988). As a result, MT3D is compatible only with block-centered finite-difference codes. For many aquifers, this type of grid mesh is sufficient to represent the aquifer properties and boundary

conditions. However, for very heterogeneous multilayered aquifers that have complex stratigraphy, grid elements of various thicknesses and shapes are required. As a result, MT3D is limited to situations where the geology can be adequately represented by a uniformly layered grid.

A second limitation of MT3D is that the code is not optimized to efficiently process the tracks of a large number of particles. MT3D, like RANDOM WALK and MOC, does not use an efficient algorithm for particle tracking. MT3D operates by tracking all the particles simultaneously using the same time-steps. In this scheme, the time-step must be selected such that no particle will move through more than one element. In some model simulations, the resident time associated with the particles in various elements differs by orders of magnitude. In this case, the smallest resident time is selected as the uniform time-step increment for all particle movement. This small time-step results in greatly increased computational run-time. This occurs with elements having large differences in their dimensions and/or velocities.

An efficient method for tracking particles through elements with variable dimensions and velocities involves a piece-wise integration over the spatial domain of each element (Kinzelbach et al., 1991; Pollock, 1989; and Scheibe, 1993). The method involves projecting a particle by nonuniform time-steps that are selected so that the particle traverses an element in a single time-step. In this method, the amount of computation required to move a particle through a velocity field depends only on the number of elements that a particle intersects along a flow path. Implicit in the application of this spatial integration, or Hamilton framework, is the asynchronous movement of the particles. Asynchronous movement in the particles makes this an efficient particle tracking method that is incompatible with the algorithms used by method-of-characteristic codes and that is difficult to implement with algorithms used by random-walk codes. Currently, no commercially available solute transport code has successfully integrated an efficient particle tracking algorithm with fully 3D random-walk algorithms.

To simulate solute transport and particle tracking in complex stratigraphy, ATS has developed and extensively used the particle-tracking code PTRAX (ECE, 1995a). PTRAX is compatible with any type of conventional numerical meshes and uses random-walk algorithms within a Hamilton framework. This provides the ability to track individual particles with or without dispersion and generate fast solute transport simulations. PTRAX is compatible with any type of numerical mesh and uses a sophisticated synchronous time-stepping scheme. A detailed code description and its algorithm validation is presented (ECE, 1995a).

3.1.4 Selection of the Computer Platform

Accurate computer modeling of the WCC aquifer requires the use of advanced numerical models and graphical tools that can incorporate large data sets. The WCC aquifer is very large and exhibits considerable spatial variation. This spatial variation, coupled with the need to simulate numerous pumping and injection wells, necessitates relatively fine numerical discretization in certain areas. The use of fine discretization corresponds to massive information throughput (i.e., very large model input and output files). Efficient preparation of the system characteristics and conditions (i.e., model input) and presentation of the results (i.e., model output) requires advanced model-building, statistical, and graphical tools. Informed decision-making based on model results relies on the effective presentation of the results. The efficiency of this process depends on many factors, including the selection of the computer platform.

ATS has gathered and/or developed an extensive collection of PC-based computer modeling tools, including a powerful suite of model-building (i.e., preprocessing) and technical presentation (i.e., postprocessing) tools.

To perform the modeling, ATS used Pentium-based computers having clock speeds of up to 400 megahertz. These computers are equipped with 512 or more megabytes (MBs) of random access memory (RAM), with a minimum of 4 gigabytes (GB) of hard drive space per machine.

3.1.5 Complementary Tools to FRAC3DVS

The computer code that forms the heart of any modeling effort is the model itself (in this case FRAC3DVS). However, other programs are necessary to make the modeling effort more flexible, efficient, and understandable. ATS has combined commercially available software packages with custom developed codes to form a set of tools for use in groundwater modeling.

Input data sets (model development) were created using the program BUILD3D (ECE, 1996a). BUILD3D can produce a 3D finite-difference grid and all of the FRAC3DVS input files. Manual errors are eliminated by the complete automation of all model input files. For instance, BUILD3D is used to locate and create the data sets for all pumping and injection wells including the location of the pumping well screen-section intervals in 3D space. In contrast, manually creating similar input files using standard software (spreadsheets, computer aided drafting (CAD) utilities, etc.) is prone to numerous errors.

Once the model input data sets are created, the actual groundwater flow and particle tracking simulations are conducted using FRAC3DVS and PTRAX. The numerical capabilities of these codes have previously been discussed. Additionally, PTRAX can create an animation file that displays particles moving through time. This type of animation was used to evaluate the spatial and temporal aspects of plume capture (or lack thereof). These animation files compress over 250 MBs of particle tracking output from a model run into a 1 to 2 MB bitmap.

There are many other postprocessing utilities that are used to graphically analyze the modeling results. Some of these utilities include AutoCAD (Autodesk, 1993) used in conjunction with QUICKSURF (Schreiber Instruments, Inc., 1994) to generate color plots of the hydraulic-head files, well velocity vectors, particle tracks, and capture zones. For 2D animations of particle tracks or concentration plumes, FIELD3D is used in conjunction with POST3D (ECE, 1996e). For detailed examination of data along horizontal or vertical slices thorough the model domain, TECPLOT (Amtec Engineering, Inc., 1994) is used in conjunction with FRAC2TEC (ECE, 1996d). To calculate average Darcy fluxes through 2-D surfaces and/or planes and average velocities within a 3-D volume, SUBSET (ECE, 1996f) is used. These programs have all been modified to directly read model output. This automatic file manipulation increases efficiency and reduces potential errors.

3.2 Model Assumptions

Every numerical model that is constructed has a set of assumptions that correspond to the equations used to develop the model. The following list of assumptions applies to the FS-1 model:

- Darcy's law applies for flow in the porous media.
- Fully saturated, 3D flow occurs in the porous media aquifer.
- The geologic material is heterogeneous and anisotropic.
- Steady-state flow occurs under both ambient and pumping conditions.
- Aquifer compaction due to pumping is not considered.
- Recharge specified on the top boundary reaches the water table instantaneously.
- Flow through the unsaturated zone is not considered.
- A single-phase, single-density fluid (water) is considered.
- Isothermal conditions exist in the porous media.
- Energy losses in the pumping and injection wells are not considered.
- Darcy's law is applicable for the high K values used in the ponds.
- Groundwater and surface water interactions are not explicitly simulated.

3.3 Model Construction

3.3.1 Hydraulic Conductivity Distribution

The K values in the FS-1 model were based on the most recent regional model (Jacobs Engineering, 1998). This model was calibrated in mid-1998 and represents the latest calibrated large-scale model of flow in the WCC aquifer. This model has incorporated much of the latest field work completed at MMR, primarily by JE. Therefore, it was decided that the most efficient way to create a representative flow field of the area was to begin with the hydraulic and physical characteristics of the regional model and refine them based on site-specific conditions.

Refinement of the physical characteristics of the model domain included a recalculation of the basal silt and bedrock surfaces based on data collected during the installation of monitoring wells for the FS-1 RI. Plan view representations of the hydraulic conductivities are shown in Figures 4 and 5. This data was also used to define additional silt and silty clay lenses which were incorporated into the model at various depths. The location of the added silt lenses is shown in Figure 6. These new lenses were assigned typical values for hydraulic conductivity for the area of 5 to 20 ft/day. Peat thickness and distribution was also incorporated in the model.

Peat thickness has been measured and mapped for the Quashnet Bog. JE has provided to ATS peat thickness for use in this modeling analysis (JE personal communication, 1998). The peat thickness was contoured (Figure 6a) and incorporated into the model with a K of 1 ft/day. This K is relatively low compared to the typical MPP sediments.

3.3.2 High K Representation of Ponds

High K values (50,000 ft/day) are used to represent the pond volumes. This is the same value used by the USGS in their WCC model (Masterson et al., 1996). The vertical K in the ponds was also set to 50,000 ft/day; however, a low K layer with horizontal and vertical K of 1 ft/day was emplaced into the model along the bottom of the ponds. These low K layers control water movement into and out of the ponds. Within the ponds these layers essentially create horizontal flow through the ponds. This limiting of the vertical inflows and outflows to the ponds is consistent with the conceptual understanding of a low-K pond bottom due to the settling of fine and organic materials.

3.3.3 Model Boundaries

The flow of groundwater in the FS-1 area was computed in the present study using the FRAC3DVS model. The FRAC3DVS computer program accepts two types of flow boundary conditions: constant head and constant flux. The computational model boundary for the FS-1 area was selected by an iterative process, working with these two boundary condition types, to minimize the effects of boundary selection on flow. The heads are known within the FS-1 Area from measured water table elevation at wells scattered throughout the region. The FS-1 area borders on three ponds (Johns, Mashpee, and Wakeby) and two rivers (Mashpee and Quashnet). Also included within the modeled area are Moody Pond and the Quashnet Bog. All of these factors were considered in developing the model boundary locations and conditions. Rivers and streams are modeled by setting a constant head boundary condition at the local water table elevation along the center of the streambed.

3.3.3.1 Constant Flux Boundaries

To set a constant flux along any portion of the model boundary, it is necessary to know the flux over the entire model depth along that portion. No such detailed flux data are available; therefore, the only viable option for a specified flux boundary segment in this case would be a "no flow" condition. The logical placement for such a condition would be along the "hinge line" of a pond or along the

centerline of a river, where it could reasonably be assumed that there is no flux perpendicular to the centerline. Several attempts were made at locating no flow boundary conditions along the east (through the estimated "hinge line" of Wakeby and Mashpee ponds and down the centerline of the Mashpee River) and west boundaries (along the estimated "divide" for Johns Pond). Several combinations were modeled, including with and without Wakeby Pond, and with and without Johns Pond. The computed velocity vectors and/or heads along the boundaries were unsatisfactory in every case.

The largest problem with these no flow boundary conditions was seen along the Mashpee River (east boundary). The computational elements created for input to the FRAC3DVS computer model were hexahedra (that is, "bricks") deformed only in the Z direction (that is, element sides forming right angles to the X and Y axes). As the east boundary along the Mashpee River is undulating, the model boundary element faces alternately switch from the north, east, and south. A no flow condition perpendicular to these alternating directions would require that the direction of flow also switch direction by 90 or even 180 degrees from one element along the boundary to the next. This effect resulted in unacceptable heads and velocities along the boundaries. This problem would be reduced, but not eliminated, by using prismatic finite elements rather than hexahedral finite difference cells. The problem is one of "scale disparity" between the flow of groundwater and the flow in the river. The FRAC3DVS code does not allow model coupling between the groundwater and surface water flows.

3.3.3.2 Constant Head Boundaries

As the constant flux boundary conditions proved unsatisfactory, the model was built using specified heads along the entire boundary. There are no measured heads along much of the model boundary; however, the water levels in Johns, Mashpee, and Wakeby ponds were known, as was the water table elevation at wells scattered throughout the FS-1 area (the April 1998 water level data were used). Figure 6b shows the measured water table contours used for the final calibration. These known heads were used to build a water table map for the entire modeled area. The only region where the water table elevation was unknown was along the northwest corner. This northwest corner will be significant in subsequent discussion. This water table map was then used to compute the heads along the boundaries. As the distribution of vertical gradients over the Area were not known, the head boundary conditions were applied as a constant over the entire model depth. The constant head boundary conditions varied along the boundary, but not with depth.

The model was then run with these constant head conditions all along the boundary, and the computed velocity vectors were plotted over the entire model. The general direction of flow for the area was known. An essentially no flow condition was expected along most of the west boundary, through the pond hinge lines, and along the Mashpee River. An essentially southward flow was expected along the north boundary of the model. This expected pattern was not seen in the first model run. Two adjustments were available to obtain this expected pattern: the water table elevation in the northwest corner and the placement of the model boundary relative to Johns, Mashpee, and Wakeby ponds. Numerous runs were made to determine the best combination of these two adjustments. During this process the model boundary was extended several times toward the north, south, and west and the water table elevation in the northwest corner was adjusted numerous times before a satisfactory flow pattern was obtained. The locations of the constant heads used for the rivers and streams are shown in Figure 7.

3.4 Plume Generation

Plume generation is a two-step process: characterization of the 3-D concentration field and creation of particle seeds. The 3-D concentration field could be constructed using a variety of mathematical methods. The method used to produce the FS-1 EDB plume is based on a 3-D wireframe. The wireframe method is particularly well suited to the FS-1 plume data because the plume is mapped as a single entity, not a series of disconnected zones of contamination. Essentially, the wireframe represents the 3-D data as continuous data (Figures 7a through 7d).

The method used to produce the FS-1 plume seeds is that of approximately constant mass particles. The particles are randomly located on a small scale (on the order of feet), but are distributed on a large scale (on the order of tens of feet), such that the number of particles near a zone of high concentration is proportionately more than the number of particles near a zone of lower concentration (Figure 7e). This method of plume seeding produces the smoothest computed concentrations over space and time while accurately representing the measured concentration data.

3.4.1 Three Dimensional Concentration Field

The 3-D concentration of the plume is described by a wireframe. The wireframe is constructed from closed polygons. The first polygon is the extent of plume boundary, as shown in the plan view (HAZWRAP, 1998, see Figure 4-9). The plan view also identifies the well locations and the cross-sections (HAZWRAP, 1998, see Figure 4-10). There are five cross-sections of the plume in the FS which pass through wells where EDB was detected. These are identified as C-C', D-D', E-E', F-F', and G-G' (HAZWRAP, 1998, see Figures 4-13 through 4-17). Three additional cross-sections were provided to ATS (Jacobs Engineering, 1998 see Figure 2-3 of the Bog Separation Project). These are identified as A-A', B-B', and C-C' (Jacobs Engineering, 1998, see Figures 2-4 through 2-6). Additional concentration data were collected at well 36MW1003A. These measurements were added to appropriate cross-sections, A-A' and C-C'. These eight cross-sections show the measured concentrations with depth and distance along the well fences. Concentration contours were drawn at 0, 0.001, 0.002, 0.005, 0.01, 0.02, 0.05, 0.1, 0.2, 0.5, 1, 2, 5, 10, and 15 parts per billion (ppb), respectively, on each cross-section where applicable. These concentration contours were then digitized, forming 218 2-D polygons. These 2-D polygons were then combined with the well fence locations to form 3-D polygons, which look like a series of intersecting bent hoops. The combination of these 3-D polygons forms the wireframe, which looks like a plume-shaped, multi-level cage. EDB concentration data were also taken at 25 drive points. Thirteen of these drive points were non-detects. These 25 measurements were added to the wireframe as individual points in 3-D space.

The Plume3D computer program, developed by ATS specifically for this task of generating plumes from wireframes, was then used to create a 3-D table of concentration representing the field. The maximum measured concentration of EDB was 15.5 ppb at well MW132A. The plan area of the plume is approximately 150 acres (0.61 km^2). The affected volume is approximately 12,000 acre-ft (15 x 106 m^3). The average concentration in the "core" is approximately 0.2 ppb. The total mass of EDB is approximately 25 lb (11 kg) times the average porosity. Assuming the average porosity is 30 %, this implies there is 7.5 lb of EDB in the groundwater. The specific gravity of EDB is 2.7 g/cm3 (22 lb/gal), so this corresponds to 0.35 gal (7.5/22) of EDB in the FS-1 plume. A previous estimate of 2.7 gal of EDB was made in the RI (HAZWRAP, 1998).

3.4.2 Plume Seeds

The plume is represented as a collection of particles seeded throughout the extent of the plume in three dimensions. The plume domain is specified by the 3-D concentration table, as generated by the Plume3D computer program. The discretization of the plume is specified by the spacing of the tabular entries in the 3 spatial coordinates. For the FS-1 EDB plume, there are 21 divisions in the X direction (east/west), 64 divisions in the Y direction (north/south), and 16 divisions in the Z direction (elevation), making a total number of 21,504 values (or "cells") in the 3-D concentration table. The spacing of the X and Y divisions are approximately equal; while the spacing of the Z divisions have a vertical exaggeration of approximately 7.

The particles are "sprinkled" randomly within each of these 21,504 cells according to the concentration at that location. The particle seeds are approximately equal in mass. The number of particles is determined by the mass indicated by the local concentration and the volume of the cell. There must be an integer number of seeds in any cell. The mass associated with a particular cell is equal to the

concentration times the volume, which is not an integer. In order for the total mass of the plume to be equal to the sum of the mass of every particle, the particle mass must vary slightly from cell to cell. The plume seeds are generated by the Seed3D computer program, which was developed by ATS specifically for this task of plume generation.

The variation of mass from the lightest particle to the heaviest is one indication of how accurately the 3-D concentration field will be modeled by particle tracking. This variation of mass is one of the statistical outputs of the Seed3D computer program. To accurately and quantitatively model the contaminant transport of the FS-1 plume, it would require approximately 500,000 seeds. However, this was not an objective of the current modeling. Accurate qualitative modeling of the plume concentration and accurate quantitative modeling of the plume capture requires approximately 50,000 seeds. The plume capture runs were made with 44,824 seeds. The figures showing individual particle tracks were made using 520 seeds, as any greater number would obscure individual tracks.

4. MODEL CALIBRATION RESULTS

The majority of the calibration efforts of the FS-1 model took place during Stage 1 of the modeling. Two water level rounds presented in the FS-1 RI were considered as potential calibration targets for the model. These water level rounds were taken in January and April 1998. The April water level round was chosen because it was a more complete dataset. Consideration was given to the 1993 JE regional water level data set but was rejected because of the paucity of data in the FS-1 region, especially when compared to the FS-1 RI data sets.

As discussed in Sections 3.6 through 3.6.2, considerable effort was made to determine the most appropriate boundary conditions for the model. In particular, the representation of the conditions along areas such as nearby ponds and rivers in the model was somewhat problematic. In order to find the best solution for the heads in these areas, a variety of boundary condition combinations were run in the model. This involved applying no flow conditions to some or all of the ponds and rivers, running the model and examining the results. In each attempt with the no flow conditions, the computed velocity vectors and/or heads along the boundaries were unsatisfactory. Therefore, the model was built using specified heads along the entire boundary (see Figures 8 and 9). These conditions were assigned from an interpolated water table based on the April 1998 water level round. Adjustments were made to the boundary in areas where information was sparse and model iterations were conducted to find the solution most representative of the April 1998 data. The final computed water table map is shown in Figure 9a.

The accuracy of the calibration was quantitatively determined by comparing the measured and computed heads at 99 observation wells measured in the April water level round (Figures 8 and 9). The root mean squared (RMS) error was 2.2 ft. The bias of all water level residuals was 0.6 ft, which implies a slight overprediction. The final total mass balance error of the model was 0.84%.

The final quantitative calibration check conducted was a flux comparison. JE flow data was available for computing the water discharge into the Quashnet Bog (See Section 2.5.2.2). A value of 3-4 mgd was determined for these measurements. Using SUBSET, an ATS flux calculator, it was determined that the model produced a flux into the Quashnet Bog of 2.79 mgd which is very close to the lower end of the measured flows. This is a reasonable match and indicates that the K/gradients/boundary conditions are producing a reasonable approximation to reality.

In summary, the FS-1 hydraulic model produces a good head match of 2.2 ft RMS and a good flux match (2.8 mgd vs 2.7 mgd). Therefore, the hydraulic model was considered ready to be used to drive the particle tracking code. The initial runs of the particle tracking model were used as a qualitative check of the calibration. Given the shape and nature of the existing plume, it was generally accepted that the plume moved nearly due north to south (with some slight easterly inflection) and discharged into the Quashnet Bog. As the reader can see in the subsequent particle track plots, this is the resulting behavior of the particle tracks.

5. MODELING RESULTS

A total of three separate modeling efforts associated with the FS-1 remediation design have been conducted by ATS from September 1998 to February 1999. For purposes of clarity of discussion, these efforts are referred to as Stages 1 (model runs 1-7), 2 (model runs 8 - 15) and 3 (model runs 16-19). The Stage 1 simulations investigated remediation of the entire plume through the use of an in-plume action, such as an axial well fence. The Stage 2 simulations focused on remediation of the areas immediately upgradient and adjacent to the K-1 Bog. Stage 3 simulations combined the systems modeled in Stages 1 and 2. A simulation run summary (Table 1) provides details of all simulations conducted to date.

5.1 Stage 1 FS-1 Modeling

Stage 1 modeling simulated the effectiveness of various in-plume remediation alternatives. The remediation scenarios were based upon a variety of extraction well configurations including both axial well fences and fences perpendicular to the plume direction (equipotential well fences). The axial well fences were generally centered along the center of mass of the plume. Reinjection of treated water was not included in this modeling. A total of seven simulations (model runs 1-7) were conducted including one no-action run and six well field designs. The well configurations for the six remediation alternatives are shown in Figures 10 - 15.

Equipotential well fences were less effective at capturing mass than axial fences. The mass recovery curves for the six remediation scenarios are shown in Figures 16 through 22. The final scenario (Run 7) predicted 70 % mass recovery within 8 years and 77 % mass recovery in 30 years. This indicates that the majority of the mass recovery occurs during the first 8 to 10 years of operation. This was generally true for each of the axial well runs. The equipotential designs do not recover mass as quickly as the axial fences because more time has to elapse for the contaminants to reach the extraction wells.

In general, the axial designs produce larger and more wide-spread drawdowns. Run 7 had the highest total pumping rate and the largest drawdown (1.67 ft) of all of the designs. The drawdown fields for all six designs are shown in Figures 10 - 15.

5.2 Stage 2 FS-1 Modeling

Stage 2 modeling simulated the effectiveness of a bog-specfic remediation alternative. Modeled remedial alternatives were selected by JE. These simulations included a pumping well (EW-05) located just south of the K-1 Bog, a series of well points representing a reinjection pipe just north of the K-1 Bog, and a similar series of well points representing an interceptor pipe just east of the K-2 Bog. The configuration of these components are shown (Figure 36). The six remediation alternatives simulated (model runs 8 - 15) tested a variety of designs. Not all simulations had, for example, the interceptor pipe included in the run. The run summary table (Table 1) provides the details of each simulation conducted.

Initial model runs included only well EW-05 and the reinjection well points so that evaluation of these components could be made without the influence of the interceptor pipe well points. A series of three runs (runs 9-11) were made under these conditions with extraction rates from EW-05 of 200, 400 and 600 gpm with reinjection of half of the extracted water. The screened interval of EW-05 was from -40 to -100 ft msl. Particle tracking results from these runs (Figures 23 - 26) showed that each was effective in deflecting most of the particles away from the K-1 Bog, with total mass capture ranging from 30 to 38 % in 30 years. Along with the no-action scenarios, plan views of these tracks are shown in Figures 27 - 30. Since only 8 % additional capture was achieved by tripling the extraction rate, a decision was made by JE personnel to use the 200 gpm extraction rate for future simulations.

For runs 12-15, the screened-section interval was moved to a lower elevation (-90 to -150 ft msl) and the 200 gpm extracted by well EW-05 was reinjected north of the K-1 Bog. For runs 13-15, the interceptor pipe was simulated in the model along the eastern edge of the K-2 Bog. This pipe was

represented by a series of well points along its length screened from 5 to 10 ft msl in runs 13 and 15 and from 30 to 35 ft msl in run 14.

Particle tracking results indicated that the well points were effective in capturing a large amount of the contaminant mass that discharges into the bogs (Figures 31 - 34). Plan views have also been provided in Figures 35 - 38. Contaminant recoveries ranging from 88 to 92 percent were achieved in 30 years. The well points screened higher in the aquifer as in runs 13 (91%) and 15 (92%) created better mass captures of 91% and 92%, respectively.

5.3 Stage 3 FS-1 Modeling

Stage 3 modeling combined the in-plume remedial system (Stage 1) with the bog-specific remedial system (Stage 2). This section provides results for the no-action case and three combination systems. Various components from the Stage 1 and 2 designs were combined. In addition to the no-action run (run 16), the three active remediation scenarios consisted of the following:

- Run 17 - A refinement of run 15 (K-1 and K-2 bog remediation only) with new locations for the reinjection pipe north of the K-1 Bog and the well points east of the K-2 Bog.
- Run 18 - The same configuration as above with addition of the 17 northernmost axial wells from run 7 pumped at 23.5 gpm instead of 37.5 gpm.
- Run 19 - The same configuration as above with addition of two reinjection wells flanking each side of the plume above the K-1 Bog.

Particle tracking results were obtained for each of these scenarios using new plume seeds with a minimum concentration of 0.05 ppb (the EDB maximum concentration level (MCL)). A total of 44,824 particle seeds were used to determine more accurate mass capture statistics under the different scenarios. A separate seed file containing approximately 500 seeds, but occupying the same 3-D area, were also run in each of these scenarios for graphical purposes. Dispersion was an active component of each model simulation.

5.3.1 No-Action Alternative

Evaluation of the no-action scenario included running the model with no remediation options active and then including a particle tracking run in the resulting flowfield. A cross-sectional view of particle tracks from the no-action scenario is shown in Figure 39. The plan view of the tracks is shown in Figure 40. The most striking feature shown in the figure is the change in direction of the particles as they move upward into the K-1 and K-2 bogs. As previously discussed in the conceptual model section of this report, the bogs are a regional groundwater discharge point. These simulation results support this assertion. The water table elevation for this area under the steady-state (no-action) case is shown in Figure 9a.

Many of the particles enter the K-1 Bog. To protect the K-1 Bog from continued contaminant loading, a series of model runs (runs 17-19) were completed. The intent of these runs was to determine if contaminants could be stopped from entering the K-1 Bog while also intercepting the significant contaminant mass that discharges to the K-2 Bog. The fate of the particle mass tracked under the no-action scenario is shown in Figure 41.

5.3.2 General Comments on Runs 17, 18, and 19

Model Runs 17, 18 and 19 have several characteristics in common including:

- the inclusion of well points along the eastern edge of the K-2 Bog;
- the inclusion of well EW-05 to the south of the K-1 Bog;

- the three 10-ft-thick silt layers located vertically beneath the bogs, and
- the series of reinjection well points north of the K-1 Bog.

The remediation design for the area along the eastern edge of the K-2 Bog specifies extraction well points spaced at 10-ft intervals, with a total pumping rate of 400gpm. In the model, however, these well points were actually spaced between 25 and 35 ft apart, with a corresponding increase in the flow rate of three times per well point to account for the 400 gpm total. This occurs because the model discretization is spaced 25 ft in the X and Y directions in this area. The increase in well point spacing was necessary for the model to be able to assign separate nodes to each well. This should not have a significant impact on the representation of these well points in the model as the superpostion effects of the well points will effectively account for the water removal in the areas between the wells.

In addition to these wells, an extraction well (EW-05) was inserted south of the K-1 Bog. In each of the three active remediation runs, this well is screened from -90 to -150 ft MSL and pumped at 200 gpm. The primary objective of the EW-05 extraction is to keep the plume deeper through this area to avoid discharge to the K-1 Bog. The vertical cross-sections of runs 17-19 (Figures 42 - 44) show that the low screened interval of the extraction well is effective in achieving this goal, as the track of the plume is generally deeper with fewer particles entering the K-1 bog compared to no-action case (run 16). One factor that may significantly impact this behavior is the lateral extent of the silt layers beneath the bogs. Although several wells have been installed in the area and a significant amount of stratigraphic information is available, the exact locations and lateral extents of the silt lenses in the area have not yet been determined. The current plan view extents of the silt layers in the model are shown in Figure 6.

Reinjection into each of the models just north of the K-1 Bog was accomplished by a series of 19 well points representing a reinjection pipeline. An evaluation of the effects of this reinjection was conducted during the Stage 2 portion of the modeling and revealed that:

1) steep vertical gradients in this natural discharge area negate the possibility of any direct interaction between the injection and extraction well systems;
2) the reinjection of the extracted water is at least partially effective in modifying the flow field in the area to divert contaminated water from the K-1 Bog;
3) at the time of this modeling, it was inconclusive as to whether the reinjection caused any lateral spreading of the plume. However, if present, the plume spreading is not excessive.

Further evaluation of the reinjection wells was not performed during Stage 3 of the modeling.

5.3.3 Run 17 - K-1 and K-2 Bog Remediation Active

As described in Section 5.3, run 17 was essentially a refinement of run 15 (K-1 and K-2 Bog remediation only) with new locations for the reinjection pipe north of the K-1 Bog and the well points east of the K-2 Bog. The total extraction rate for this scenario is 600gpm and 200 gpm is reinjected. The remaining 400 gpm would be piped to two in-stream bubblers. A plan view of extraction well and reinjection well configurations for run 17 is shown in Figure 45.

The maximum drawdown for this scenario was 0.43 ft (Figure 46). No mounding was recorded. The particle track cross-section (Figure 42) shows the visible deflection of the plume along with some mass capture.

The run 17 particle tracks are shown in Figure 45. Approximately 80 to 90 % of the total mass captured by the extraction wells occurs during the first 3 to 5 years of operation (Figure 47). The incremental mass capture and average concentration per period is shown in Figure 47a. The rate of capture rapidly declines after this time and the system begins extracting mostly clean water.

5.3.4 Run 18 - K-1 and K-2 Bog Remediation Active with Additional Axial Wells

Run 18 was a version of run 17 enhanced by including 17 axial wells. These wells correspond to wells EW-07 through EW-23 in run 7 of the Stage 1 modeling, with a total extraction rate of 400 gpm. The purpose of these wells is to quickly extract as much contaminant mass as possible. The total extraction rate for this scenario was 1000 gpm and the total reinjection rate was 200 gpm. The remaining 800 gpm would be piped to two in-stream bubblers. A plan view of extraction well and reinjection well configurations for run 18 is shown in Figure 48.

The particle tracks in plan view (Figure 49) and cross section (Figure 43) are similar to the figures from run 17, with the additional mass capture by axial wells shown.

The maximum drawdown was 0.62 ft, which occurred near the middle of the axial well fence (Figure 48). No mounding was recorded in this scenario.

The mass capture percentages from this run (Figure 50) show that the addition of these axial wells increases the total mass capture to 85%, although as in run 17, most of the mass captured occurs within the first 3 to 5 years. The incremental mass capture and average concentration per period is shown in Figure 50a.

5.3.5 Run 19 - K-1 and K-2 Bog Remediation Active with Additional Axial Wells and Reinjection

Run 19 was identical to run 18 with the exception of the addition of four reinjection wells flanking either side of the plume north of the K-1 Bog. The reinjection rates for these wells was 100 gpm each. The purpose of these wells is to help provide clean water the the future Mashpee municipal water supply well in this area and to help narrow the plume width upgradient of the K-1 Bog.

The total extraction rate for this scenario is 1,000 gpm and the total reinjection rate is 600 gpm. The remaining 800 gpm would be piped to two in-stream bubblers. A plan view of extraction well and reinjection well configurations for run 19 is shown in Figure 51.

The maximum drawdown was 0.42 ft, which occurred near the northern end of the axial well fence (Figure 51). This shift in the maximum drawdown in comparison to run 18 was due to the mounding produced by the 100 gpm reinjection wells. The maximum mounding was 0.34 ft, which occurred at the northeastern 100 gpm reinjection well.

The reinjection wells effectively negated the four southernmost axial wells, thereby making this design less efficient than run 18. The recirculation of reinjected water between the reinjection and extraction wells occurs, which obviously lowers the capture efficiency of the extraction system. The plan and cross-section views for this scenario are shown in Figures 52 and 44, respectively.

The mass capture percentages from this run (Figure 53) show that the total capture percentage (85%) is approximately the same as run 18. The incremental mass capture and average concentration per period for run 19 is shown in Figure 53a.

5.3.6 Run 20 - K-1 and K-2 Bog Remediation Active with Additional Axial Wells and Reinjection with P-11 Well Activated After 10 years

Run 20 was identical to run 19, including the four reinjection wells flanking either side of the plume north of the K-1 Bog, except that the proposed Mashpee public water supply well number P-11 was activated using an extraction rate of 350 gpm after 10 years. The maximum drawdown was 1.9 ft, which occurred at the P-11 well. The predicted drawdowns and mounding are shown in Figure 54.

The plan and cross-section views for this scenario are shown in Figures 55 and 56, respectively. The P-11 well did not capture any mass (i.e. particles) due to the fact that the well does not begin operation until 10 years from now and because most of the mass is extracted prior to the well being turned on. It should be noted that all the contaminant transport processes were not modeled, therefore the plume migration times are only approximate.

The mass capture percentages from this run (Figure 57) show that the total capture percentage (85%). The incremental mass capture and average concentration per period is shown in Figure 57a.

5.3.7 Run 21 - K-1 and K-2 Bog Remediation Active with P-11 Well Activated After 10 years

Run 21 was identical to run 17 with the exception of the activation of the P-11 well after 10 years. A plan view of the extraction well and reinjection well configurations for run 21 is shown in Figure 59.

The maximum drawdown for this scenario was 2.2 ft at the P-11 well (Figure 58). No mounding was recorded. The particle track cross-section (Figure 60) shows the visible deflection of the plume along with some mass capture.

The run 21 particle tracks are shown in Figure 59 for the plan view and Figure 60 for the cross-section. Approximately 80 to 90 % of the total mass captured by the extraction wells occurs during the first 3 to 5 years of operation (Figure 61). The incremental mass capture and average concentration per period is shown in Figure 61a. As with run 20, the P-11 well does not receive any mass because most of the mass is extracted prior to the well being turned on.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A refined flow and mass tracking model of the FS-1 Plume and Quashnet Bog has been developed. With this model, a range of alternatives and no-action scenarios was evaluated. The following conclusions are based on an evaluation of the FS-1 modeling results:

1) Several new silt lenses have been added to the model in the Quashnet Bog area. This refinement provides a more accurate assessment of plume capture, evaluation of vertical plume migration and well screen placement.
2) A preliminary evaluation of the proposed Mashpee public water supply well number P-11 area pump test was conducted and it was determined that the Ks derived from the test were substantially lower (i.e. 2 to 4 times lower) than the Ks used in the regional model (and subsequently this model).
3) The selected remedial alternative removes approximately 85% of the EDB mass over 30 years in the model simulations.
4) Approximately 90 to 95% of all the mass predicted to be extracted will be removed within 5 to 6 years from the start of pumping for most of the alternatives.
5) The upgradient axial well reinjection inundated the extraction system between the reinjection wells. However, due to the natural horizontal gradients, the mass capture is not significantly impacted. The reinjection may also mitigate any adverse impacts on Moody Pond and smaller area bogs by reducing the drawdown.
6) The P-11 well does not capture any EDB mass from the FS-1 plume, primarily due to most of the mass being extracted prior to the P-11 well being activated.

6.2 Recommendations

1) Given the good RMS (RMS = 2.2 ft) and matching of the discharge to the Quashnet Bog, further evaluation of the P-11 pump test results are needed to determine their use in regional modeling. A study to confirm/refine the P-11 pumping test should be conducted.
2) Any active extraction/reinjection scheme should probably only operate for 8-10 years due to the diminishing annual mass captures.
3) Runs 18 and 19 have similar efficiencies based on mass capture and drawdown results. However, run 18 is the recommended remedial alternative as additional reinjection wells are not required.

4) Further refinement of the extraction system may be warranted for the wells between the axial reinjection wells.
5) Additional groundwater data is necessary to further define the plume between the source and the Quashnet Bog.

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FIGURES AND TABLES

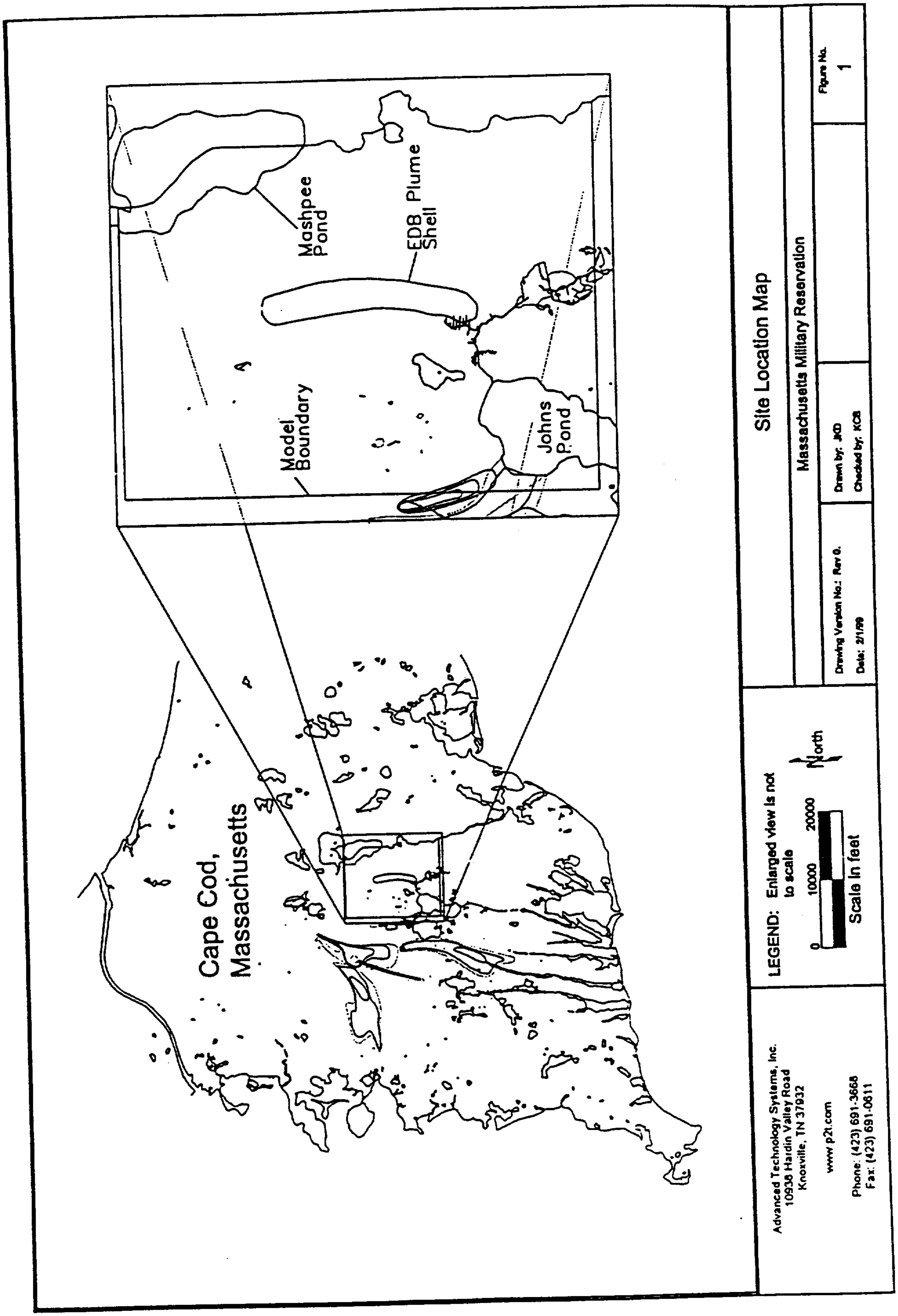


Figure 1. Site Location Map

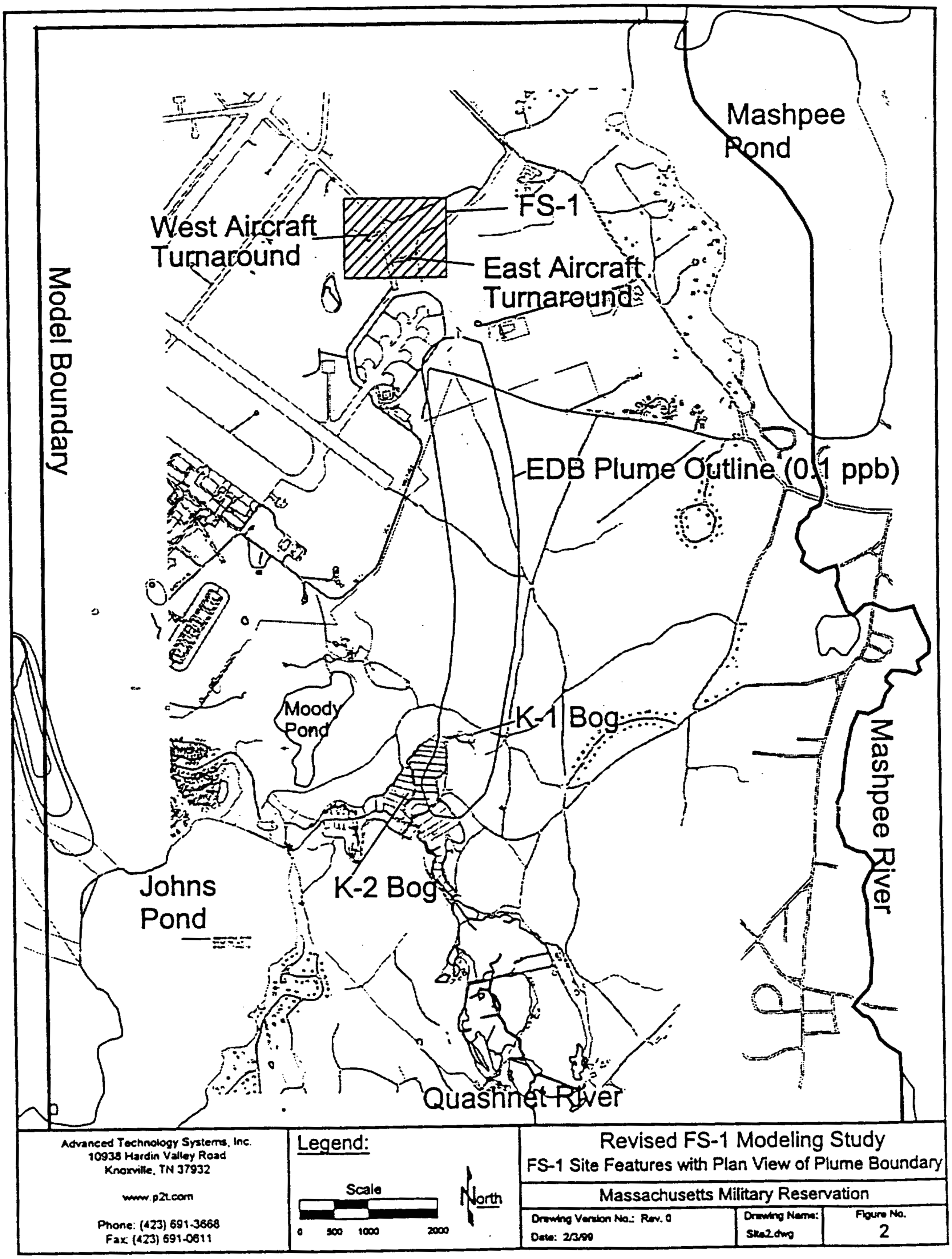


Figure 2. FS-1 Modeling Study, FS-1 Site Features with Plan View of Plume Boundary

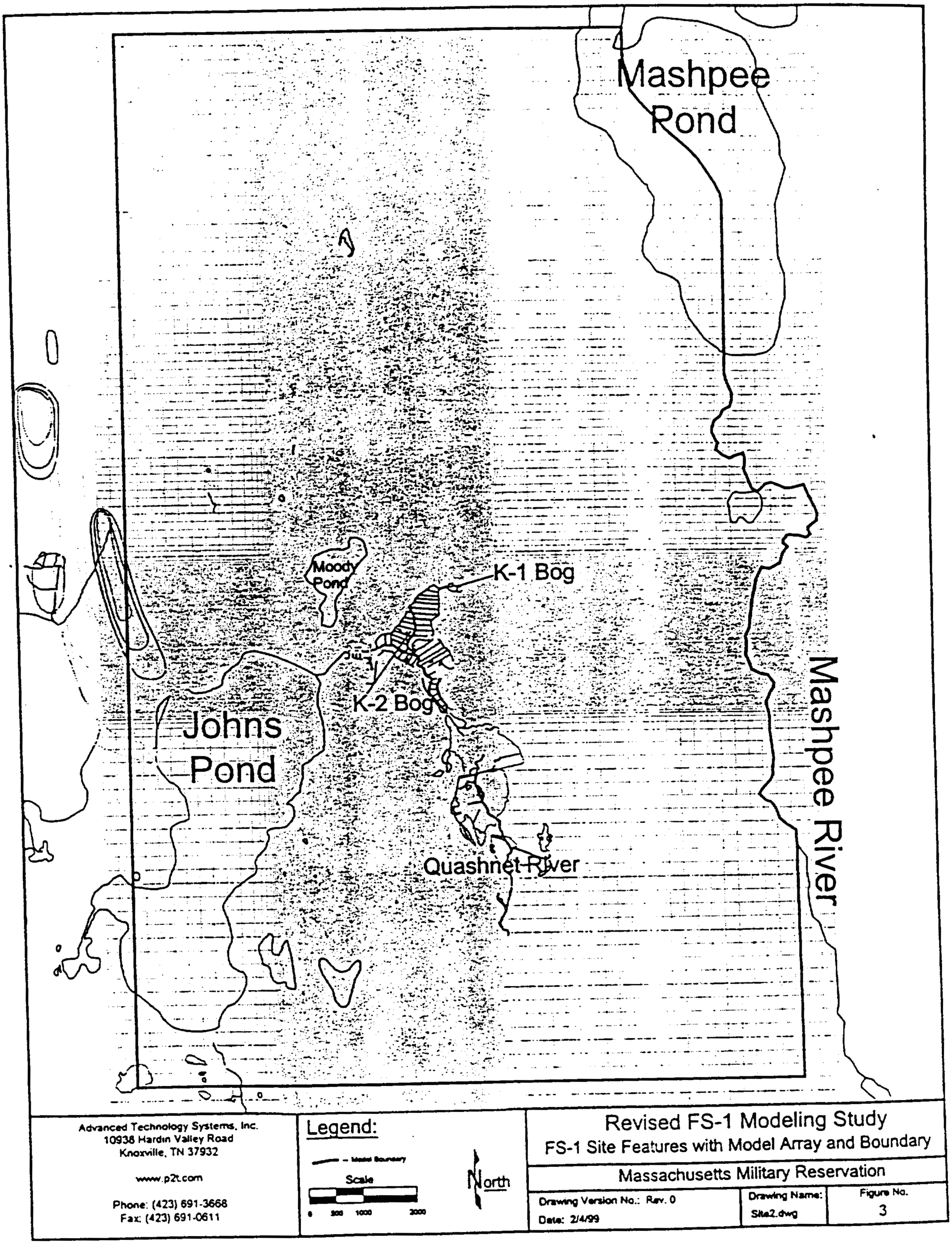


Figure 3. Revised FS-1 Modeling Study, FS-1 Site Features with Model Array and Boundary

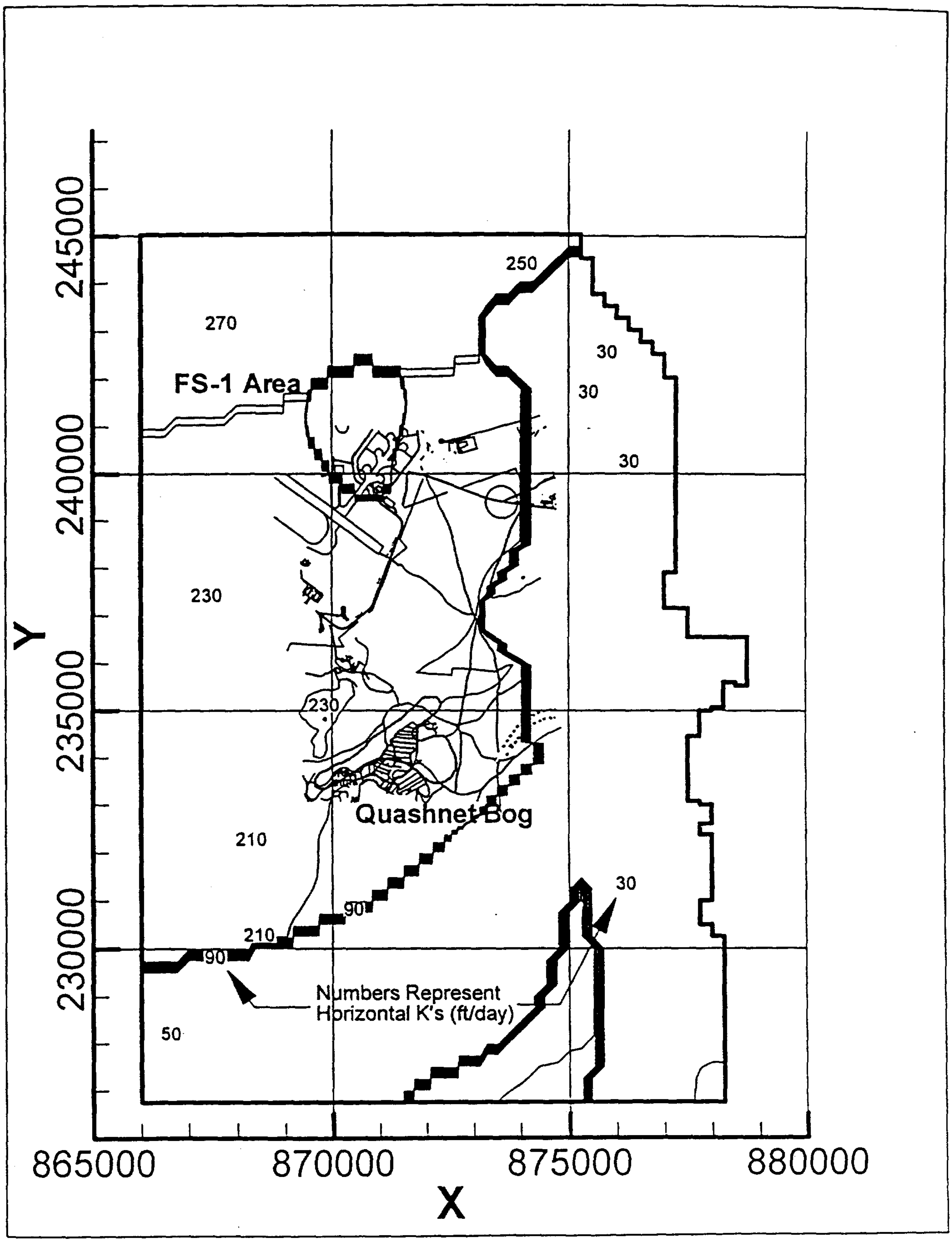


Figure 4. Plan View of Hydraulic Conductivity Field at Layer 5

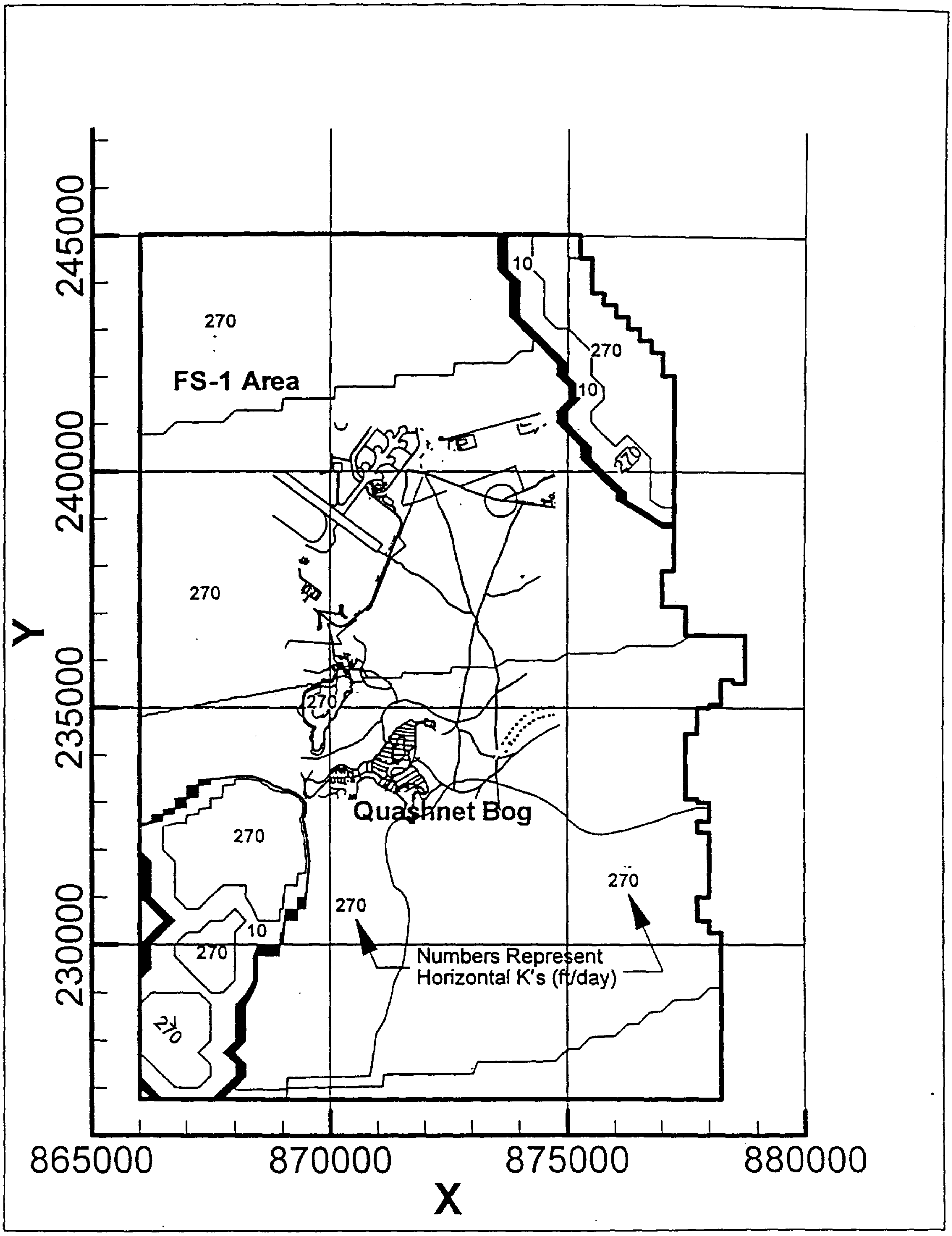


Figure 5. Plan View of Hydraulic Conductivity Field at Layer 23

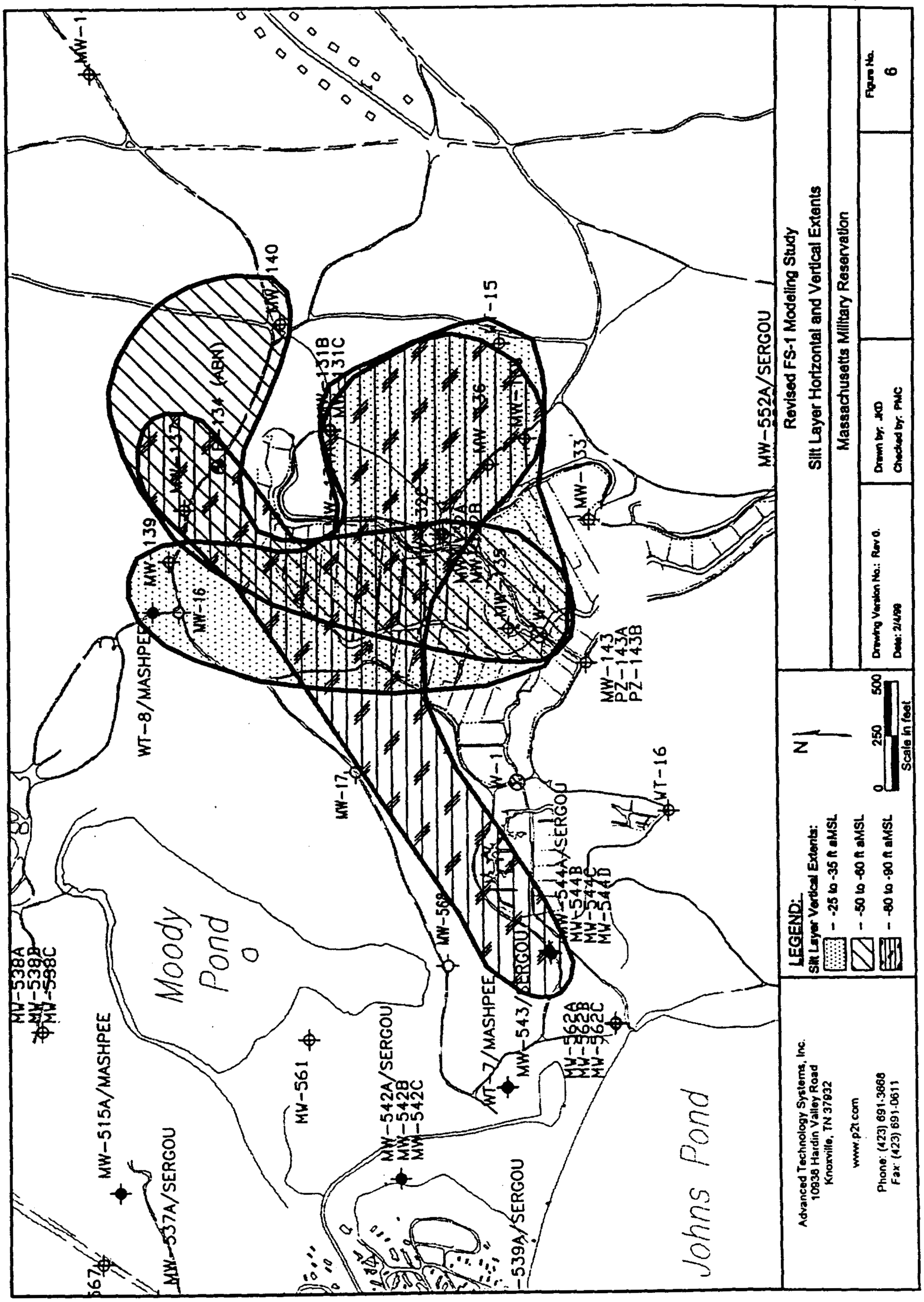
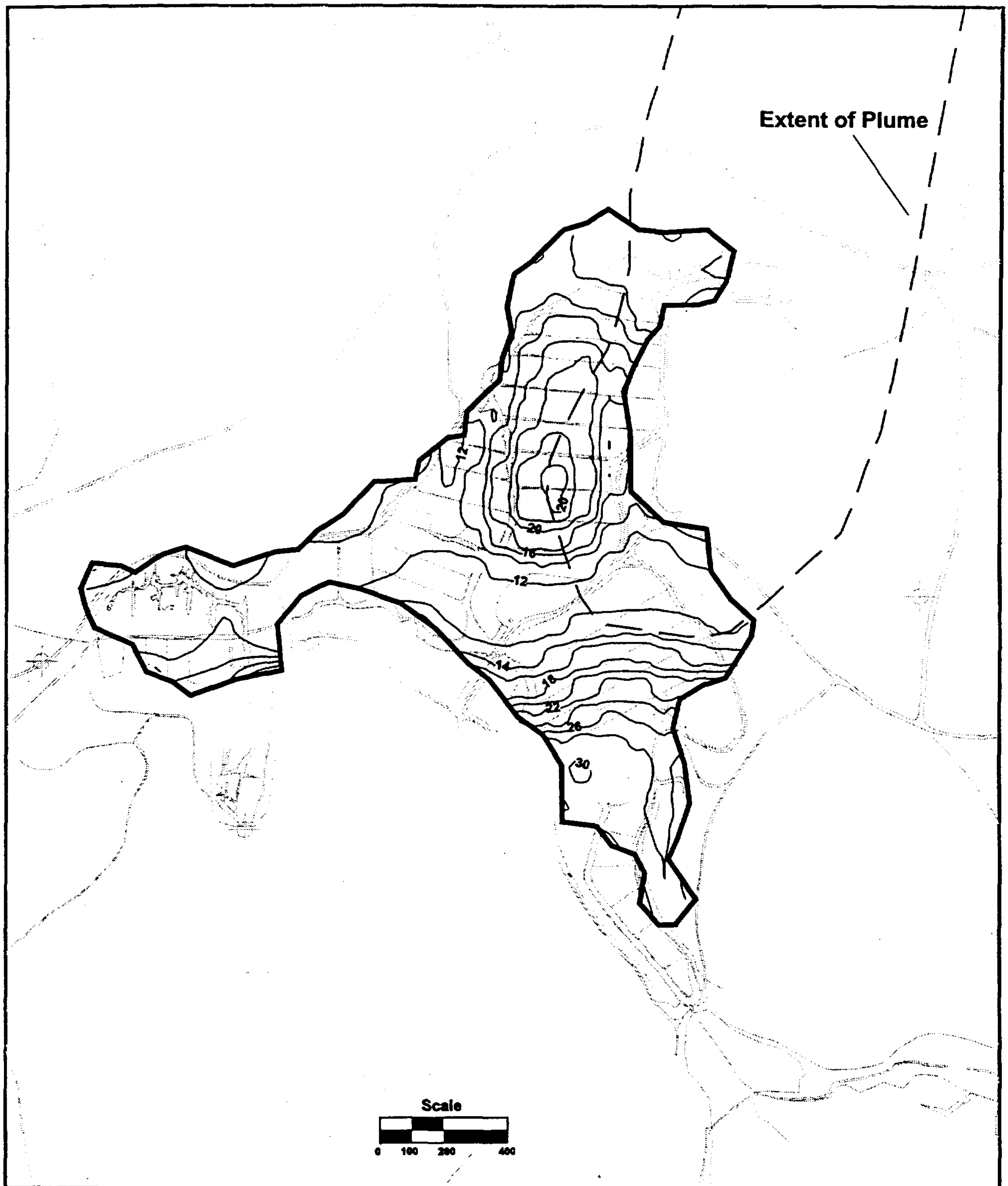


Figure 6. Revised FS-1 Modeling Study, Silt Layer Horizontal and Vertical Extents



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: North 30 Peat Bog Thickness Contour	**Revised FS-1 Modeling Study** **Quashnet Peat Bog Thickness Contours** **Massachusetts Military Reservation** Drawing Version No.: Rev. 1 Date: 4/7/99	Drawing Name: Peatbog.dwg Figure No.

Figure 6a. Revised FS-1 Modeling Study, Quashnet Peat Bog Thickness Contours

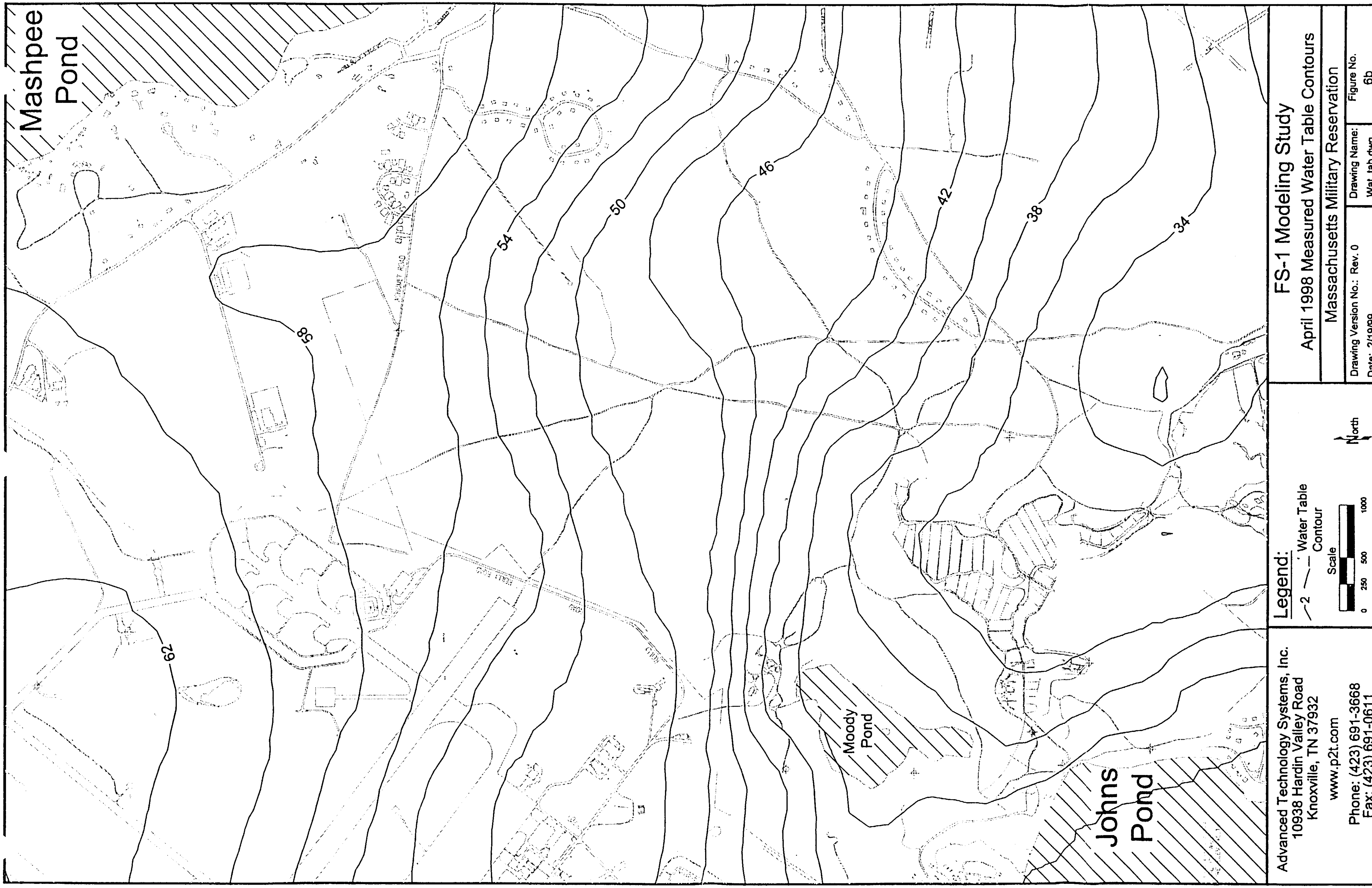
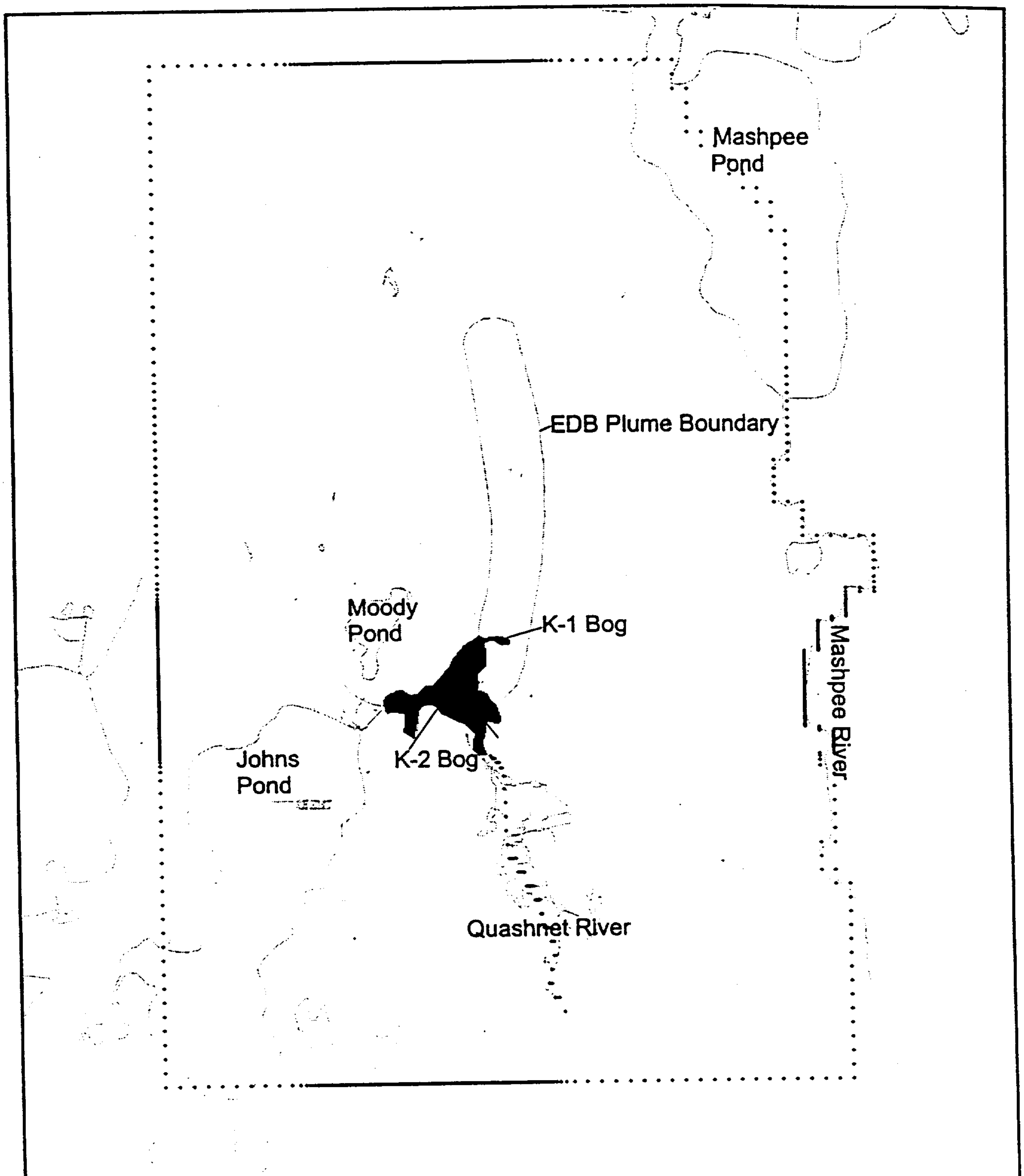


Figure 6b. FS-1 Modeling Study, April 1998 Measured Water Table Contours



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Legend:
◆ –Constant head node

Scale
0 500 1000 2000

North

FS-1 EDB Plume Modeling
FS-1 Constant Head Nodes

Massachusetts Military Reservation

Drawing Version No.: Rev. 0	Drawing Name:	Figure No.
Date: 2/4/99	Site2.dwg	7

Figure 7. FS-1 EDB Plume Modeling, FS-1 Constant Head Nodes

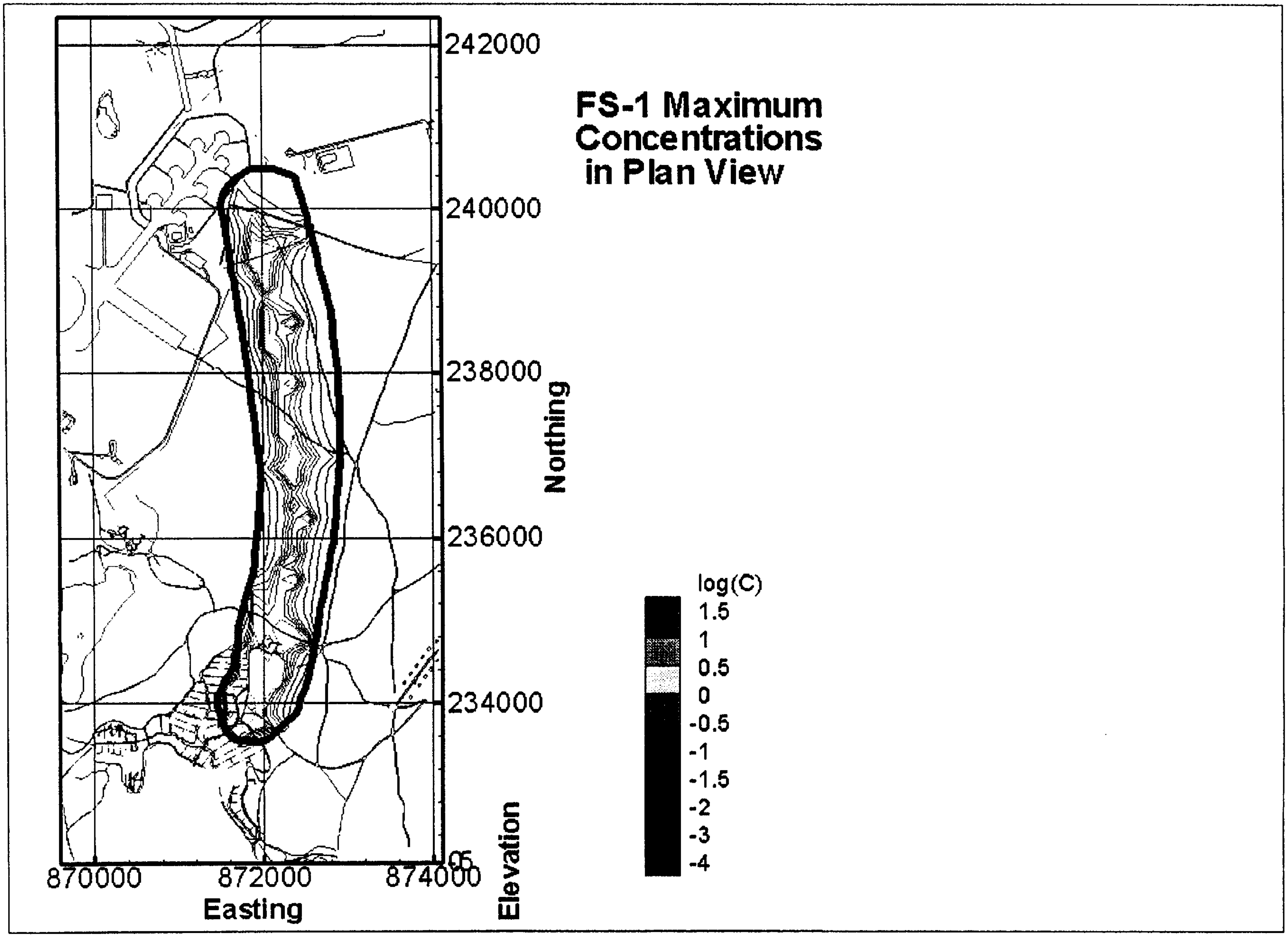


Figure 7a. Plan View of Maximum Concentrations

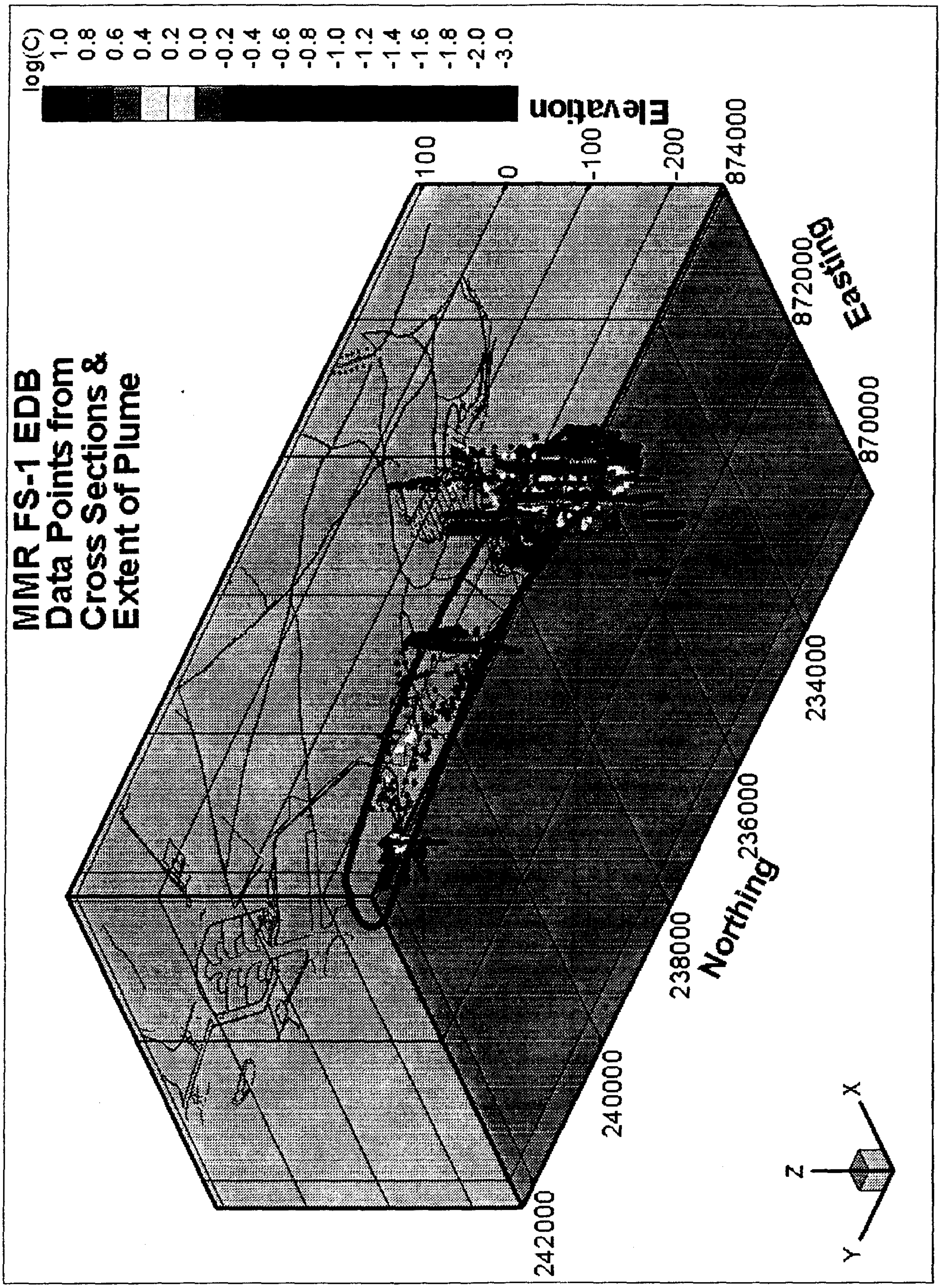


Figure 7b. Data Points from Cross Sections and Extent of Plume

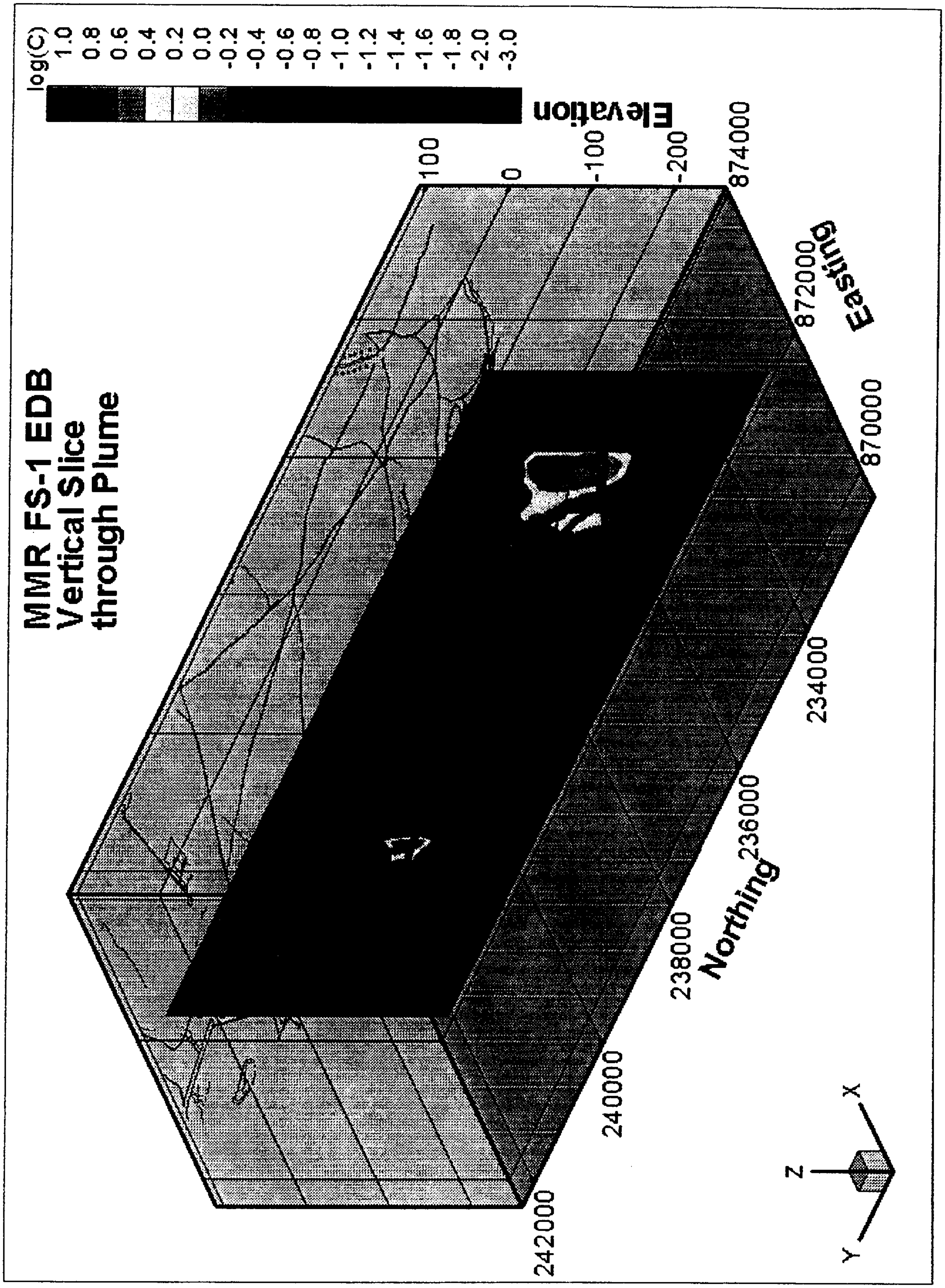


Figure 7c. Vertical Slice through Plume

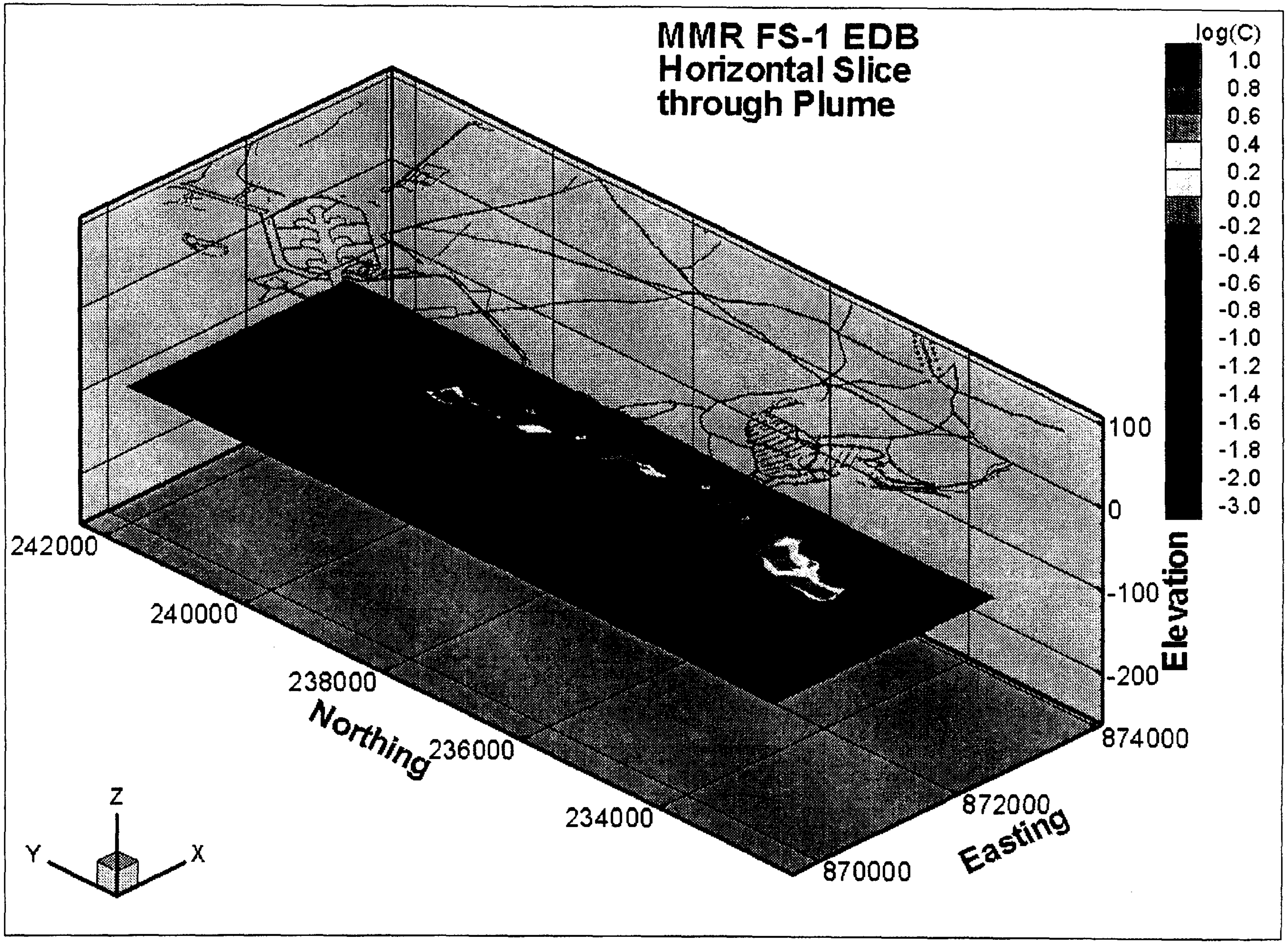


Figure 7d. Horizontal Slice through Plume

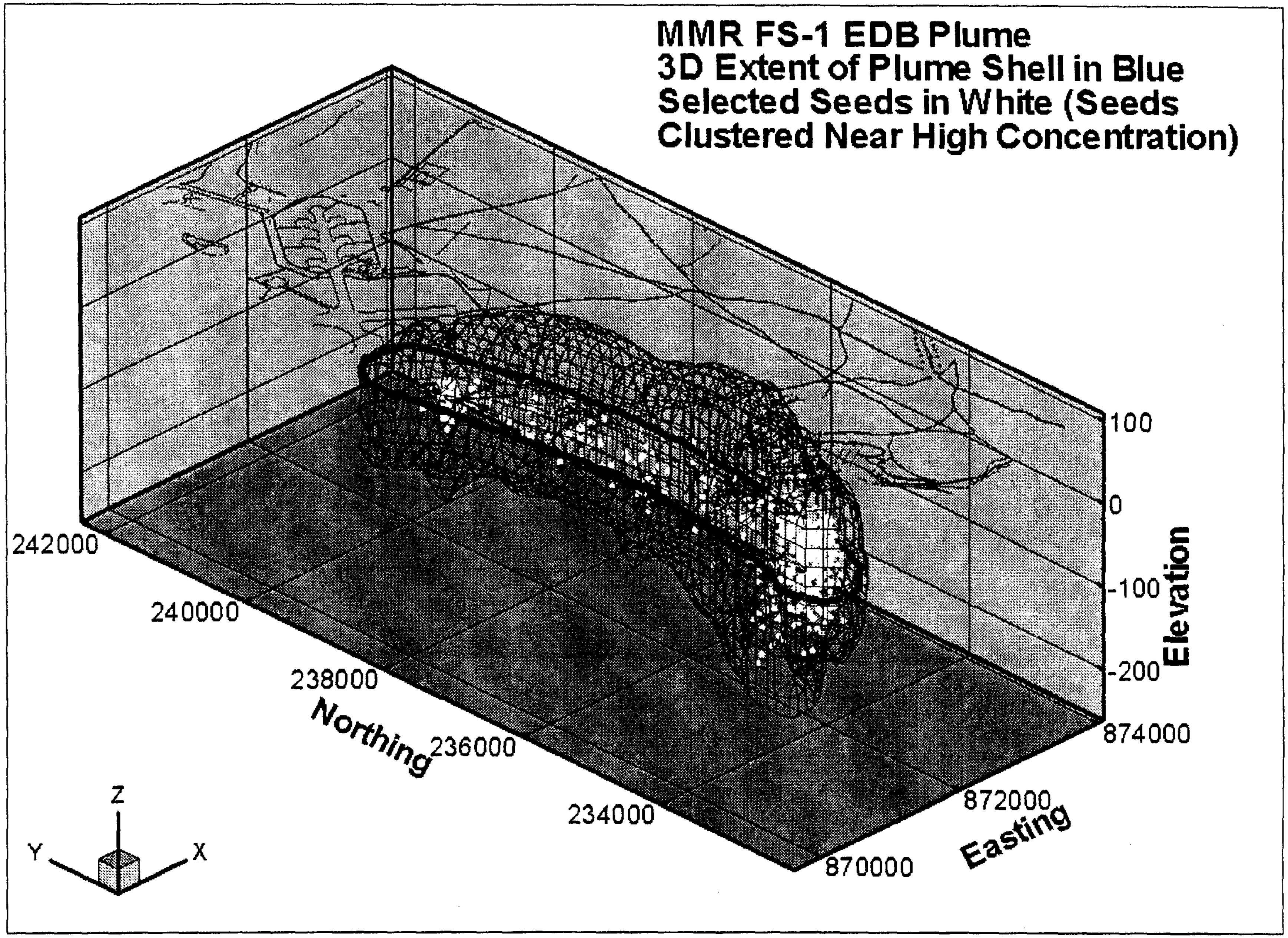
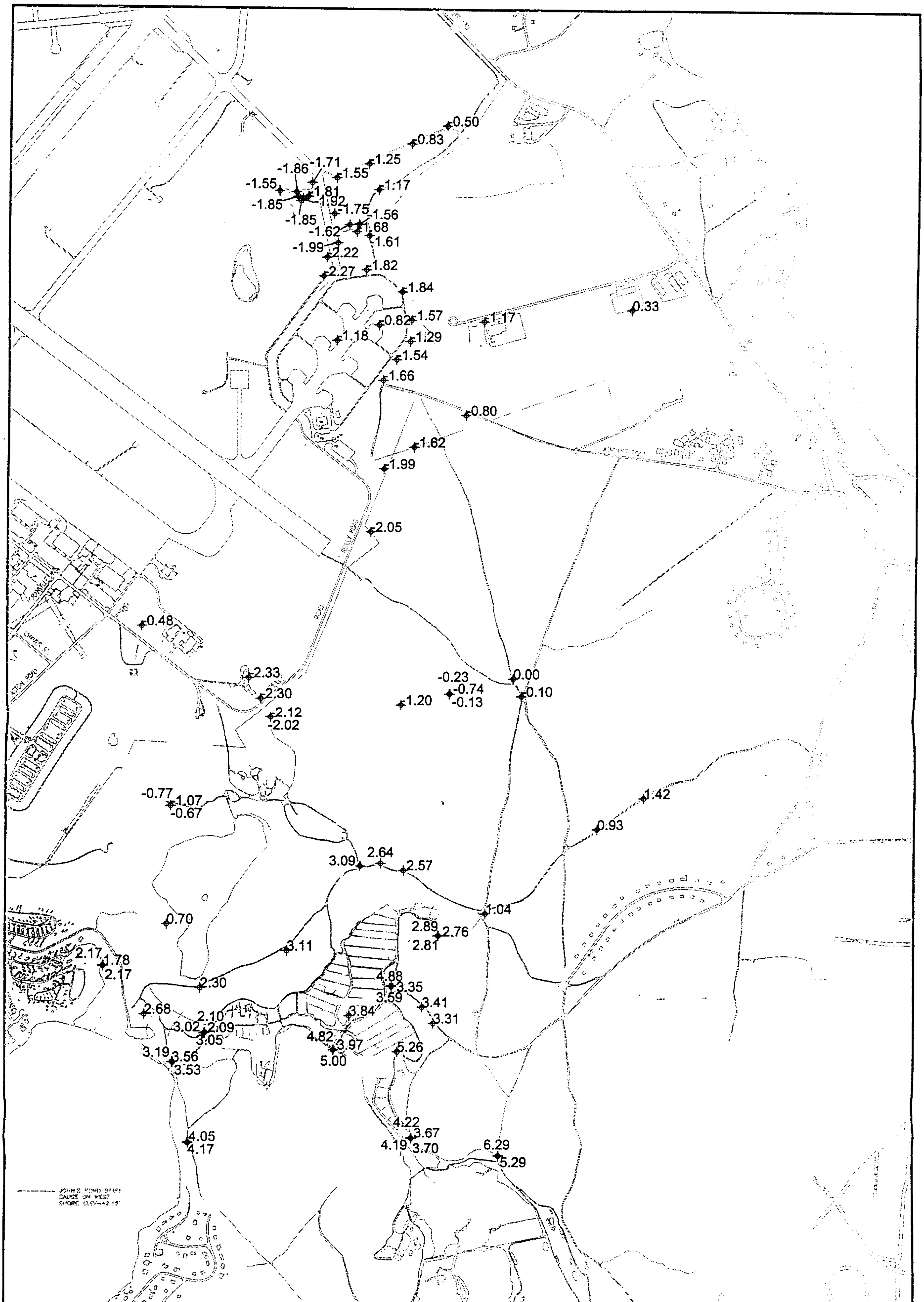


Figure 7c. 3D Extent of Plume Shell with Seeds

Figure 8. Revised FS-1 Modeling Study, Steady State Residual Heads



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Legend:

North

⌖ — Monitoring Well

Scale in Feet
0 250 500 1000

Revised FS-1 Modeling Study
Steady State Residual Heads

Massachusetts Military Reservation

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Date: 1/28/99	Residual.dwg	8

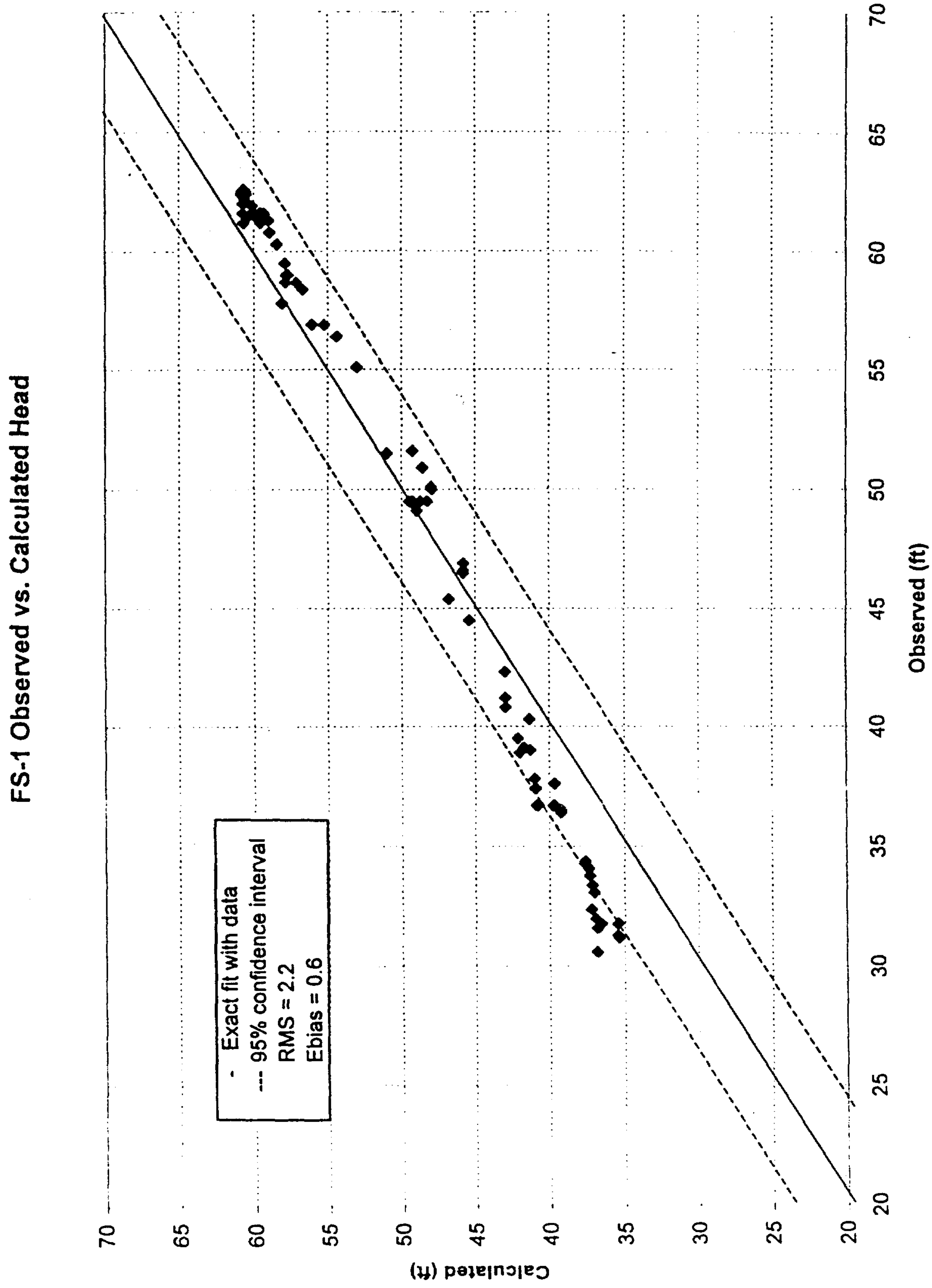
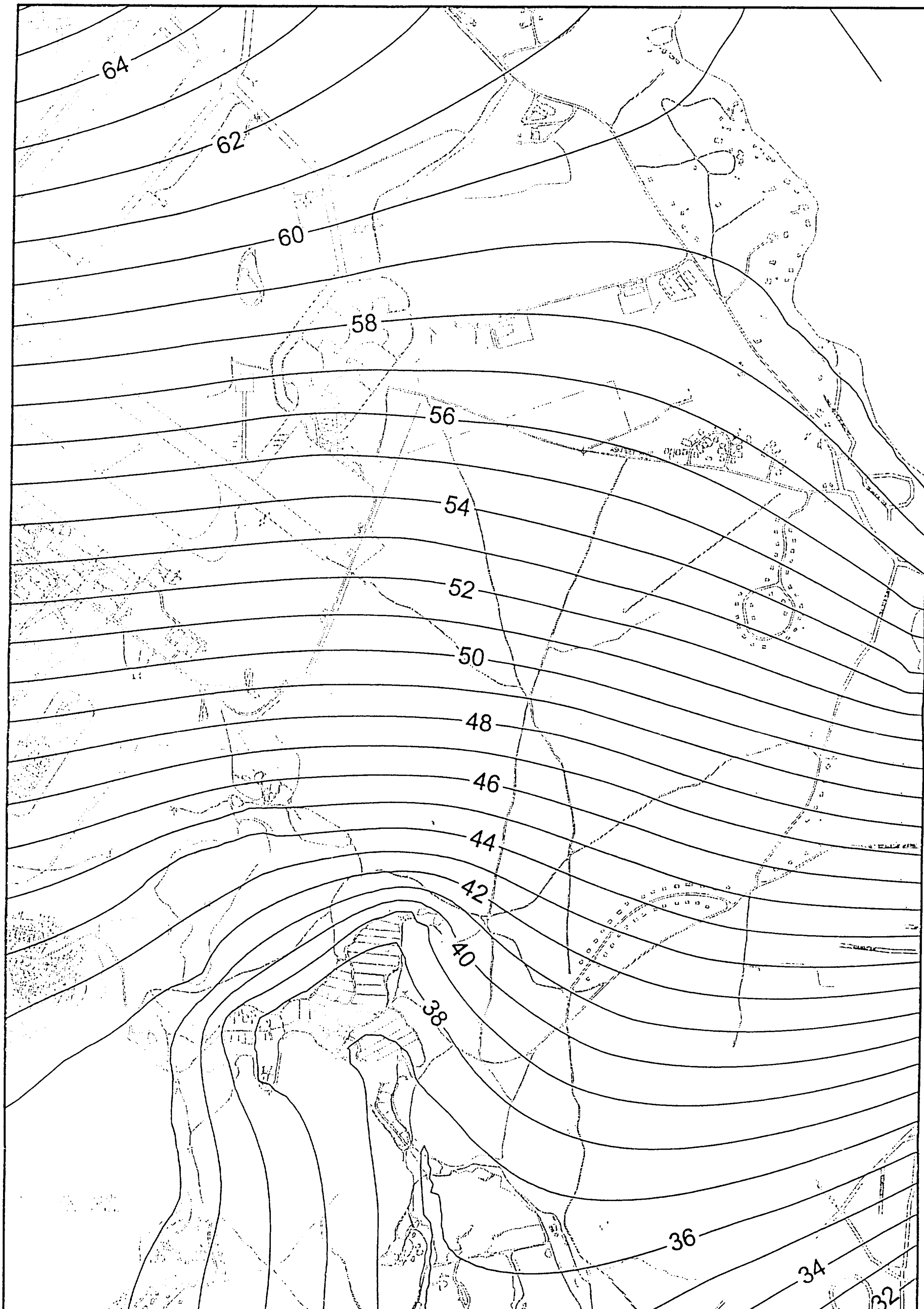


Figure 9. FS-1 Observed vs Calculated Head

Figure 9a. Revised FS-1 Modeling Study, Steady State Water Table Contours



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Legend:
62 — Water Table Contour (ft MSL)

North

Scale in Feet
0 250 500 1000

Revised FS-1 Modeling Study
Steady State Water Table Contours

Massachusetts Military Reservation

Drawing Version No.: Rev. 0	Drawing Name:	Drawing No.
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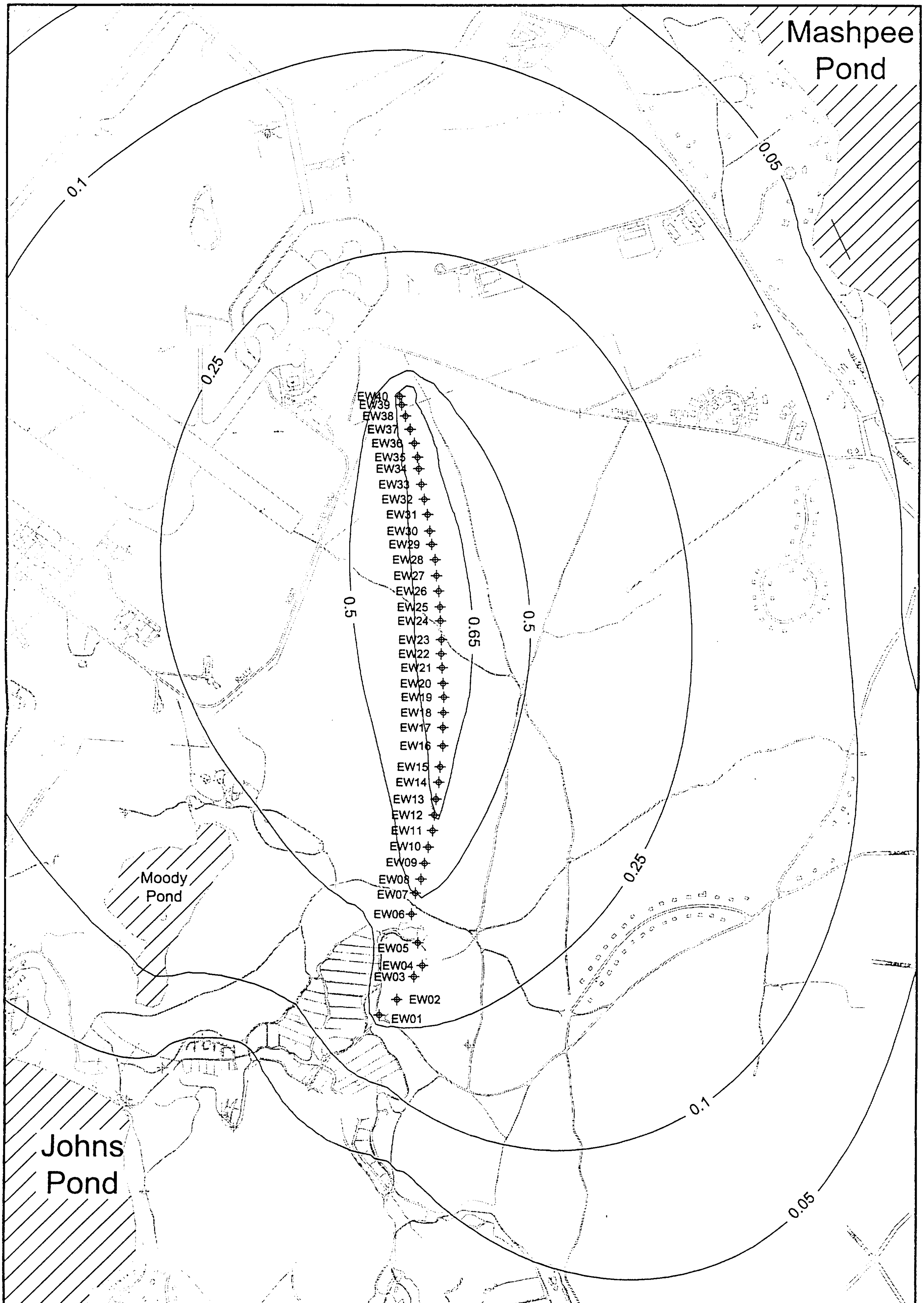


Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: Scale 0 250 500 1000 0.5 — Drawdown Contour EW-07 — Extraction Well North	FS-1 Stage 1 Modeling Run 2 - Well Configuration and Drawdown Massachusetts Military Reservation Drawing Version No.: Rev. 0 Date: 2/4/99 — Drawing Name: Drawdown.dwg — Figure No. 10

Figure 10. FS-1 Stage 1 Modeling, Run 2 – Well Configuration and Drawdown

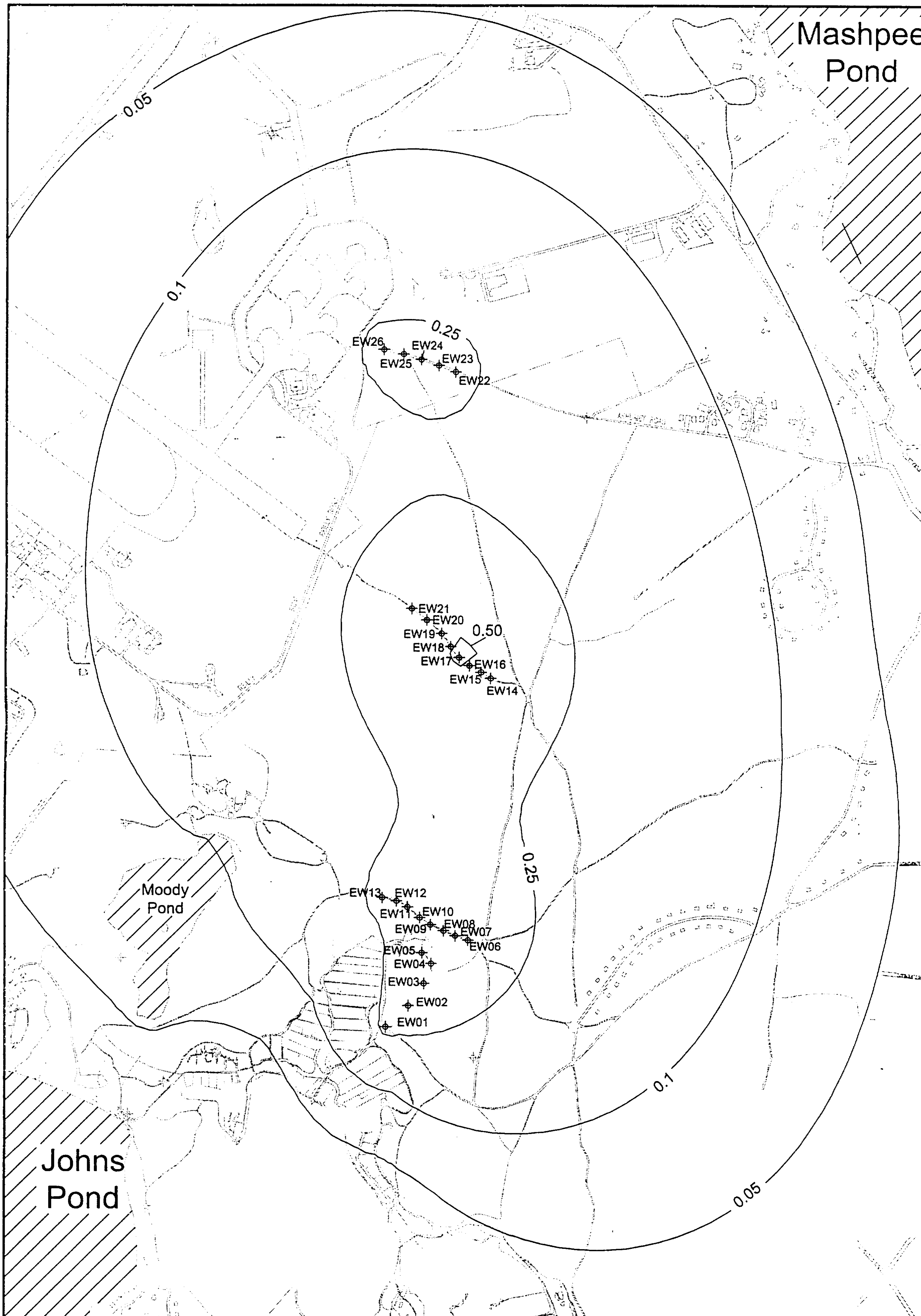


Figure 11. FS-1 Stage 1 Modeling, Run 3 – Well Configuration and Drawdown

Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: Scale 0 250 500 1000 0.5 Drawdown Contour EW-07 Extraction Well North	FS-1 Stage 1 Modeling Run 3 - Well Configuration and Drawdown Massachusetts Military Reservation Drawing Version No.: Rev. 0 / Date: 2/4/99 Drawing Name: Drawdown.dwg Figure No. 11

Figure 12. FS-1 Stage 1 Modeling, Run 4 – Well Configuration and Drawdown

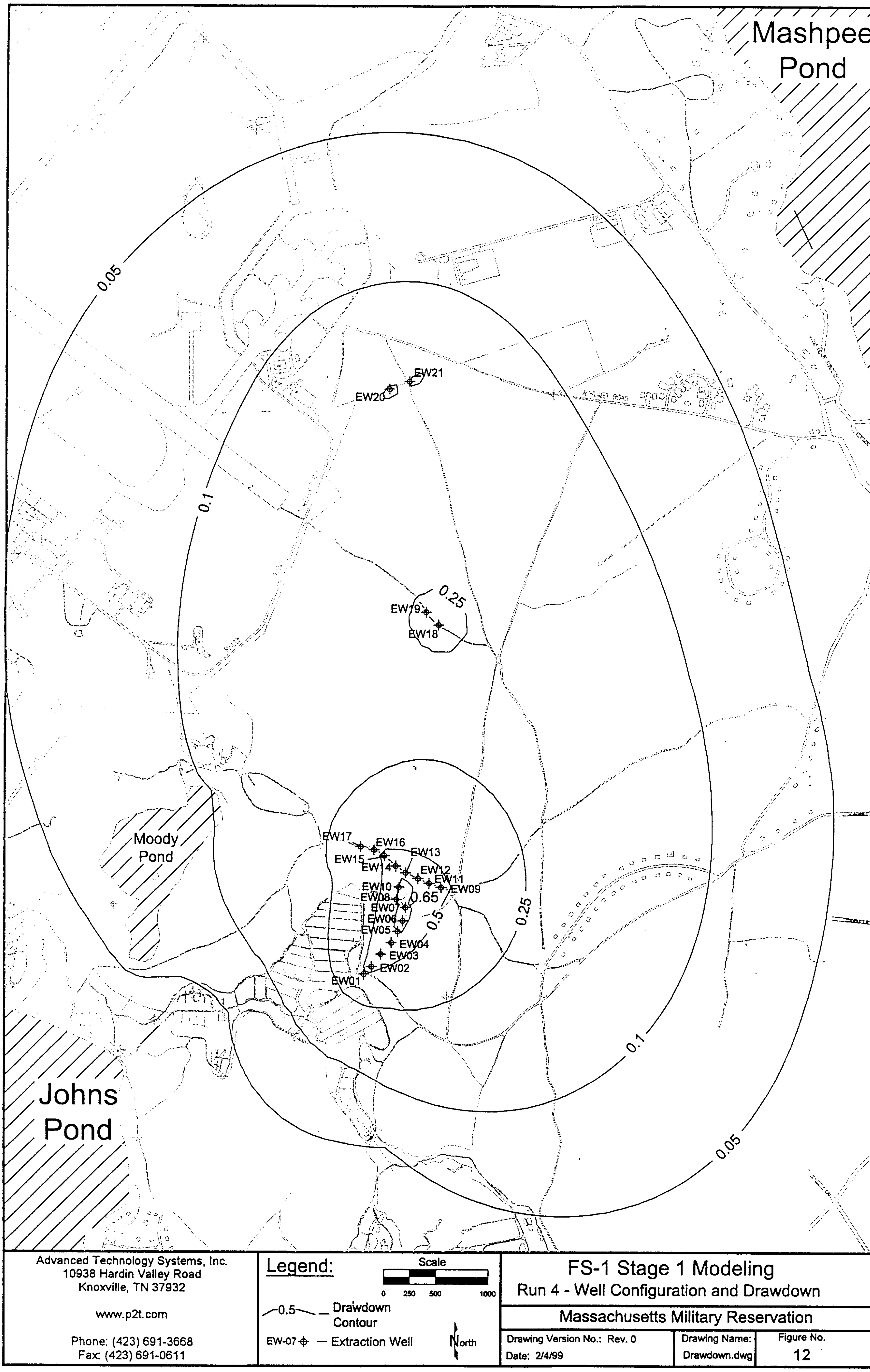
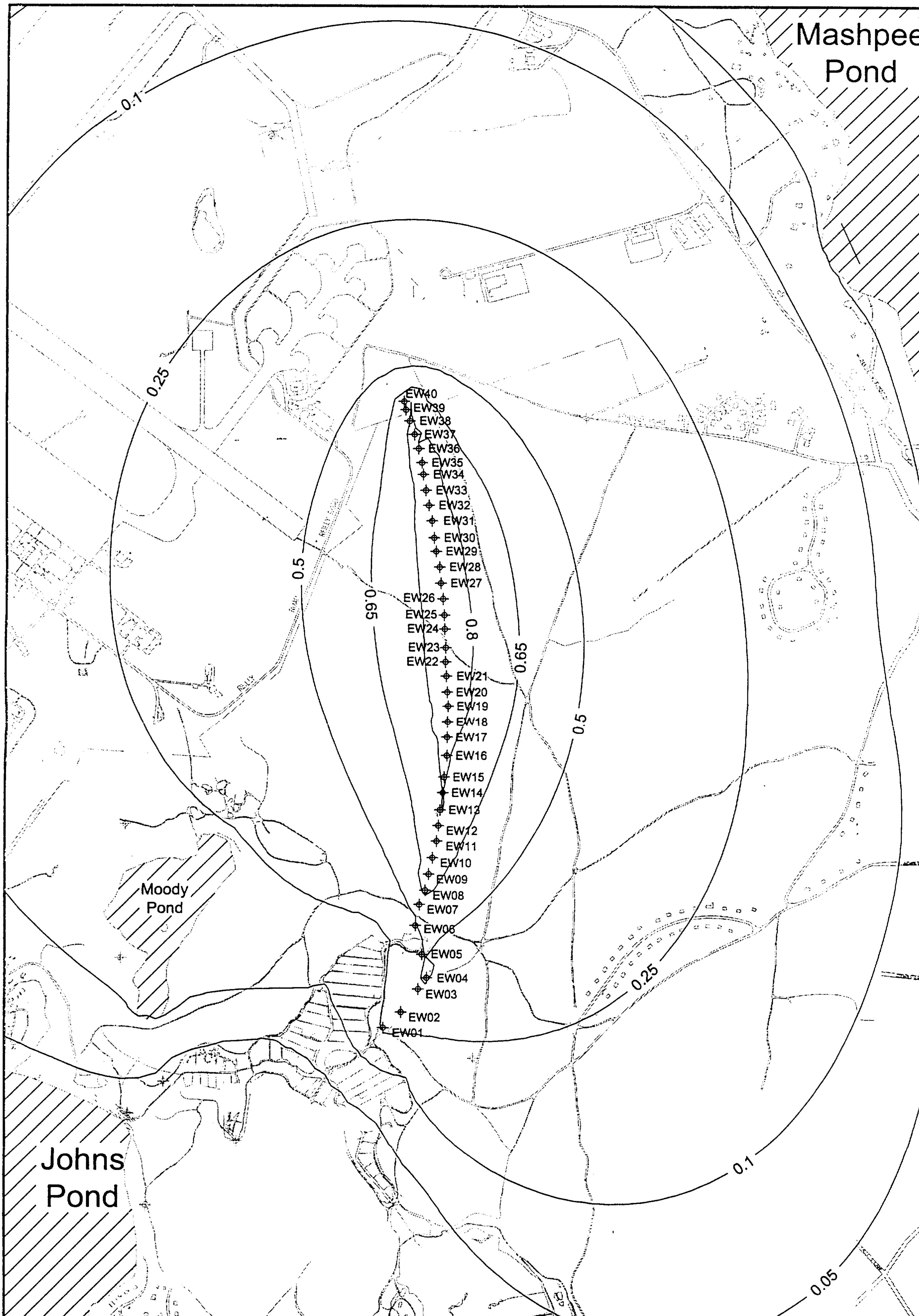
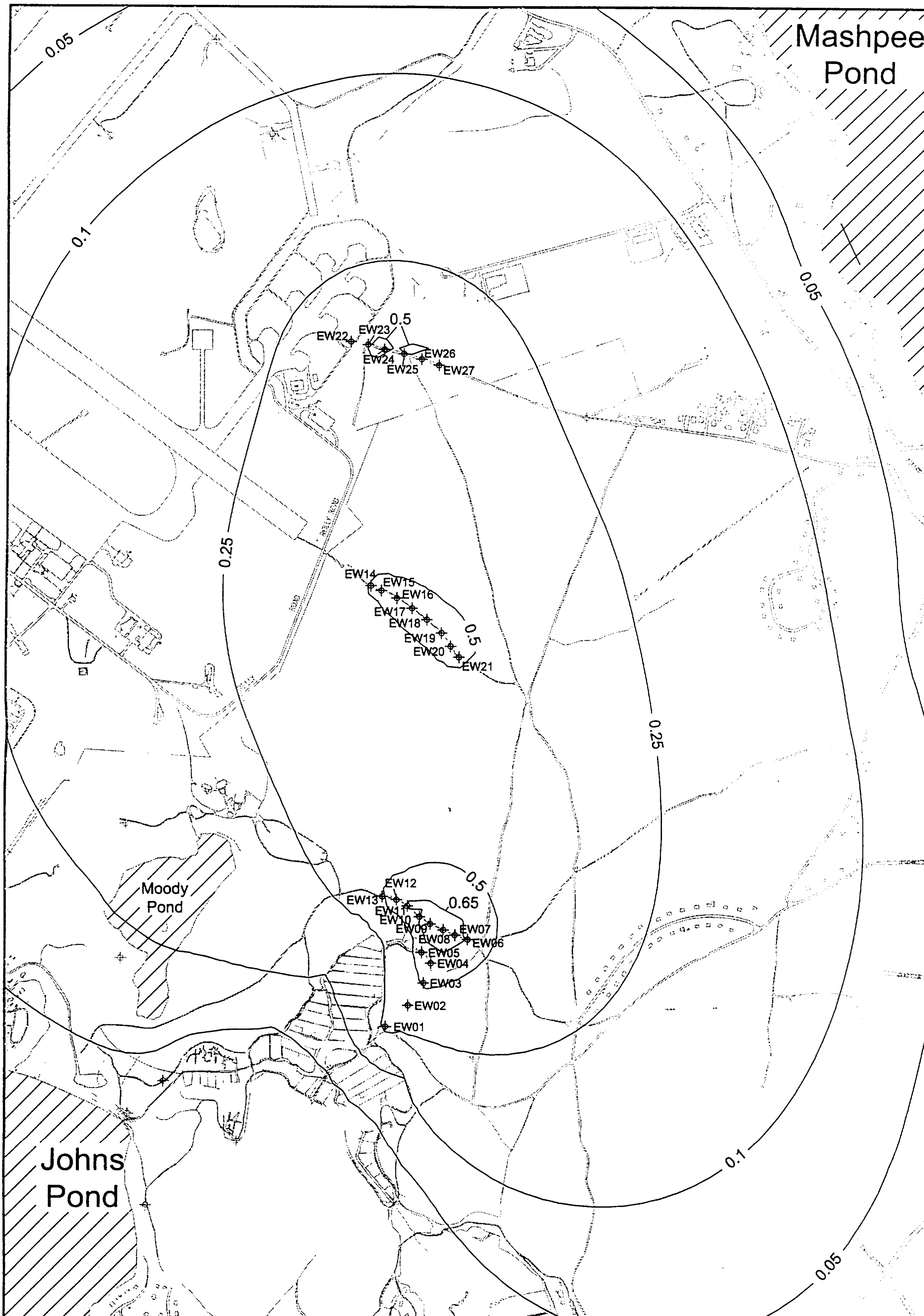


Figure 13. FS-1 Stage 1 Modeling, Run 5 – Well Configuration and Drawdown

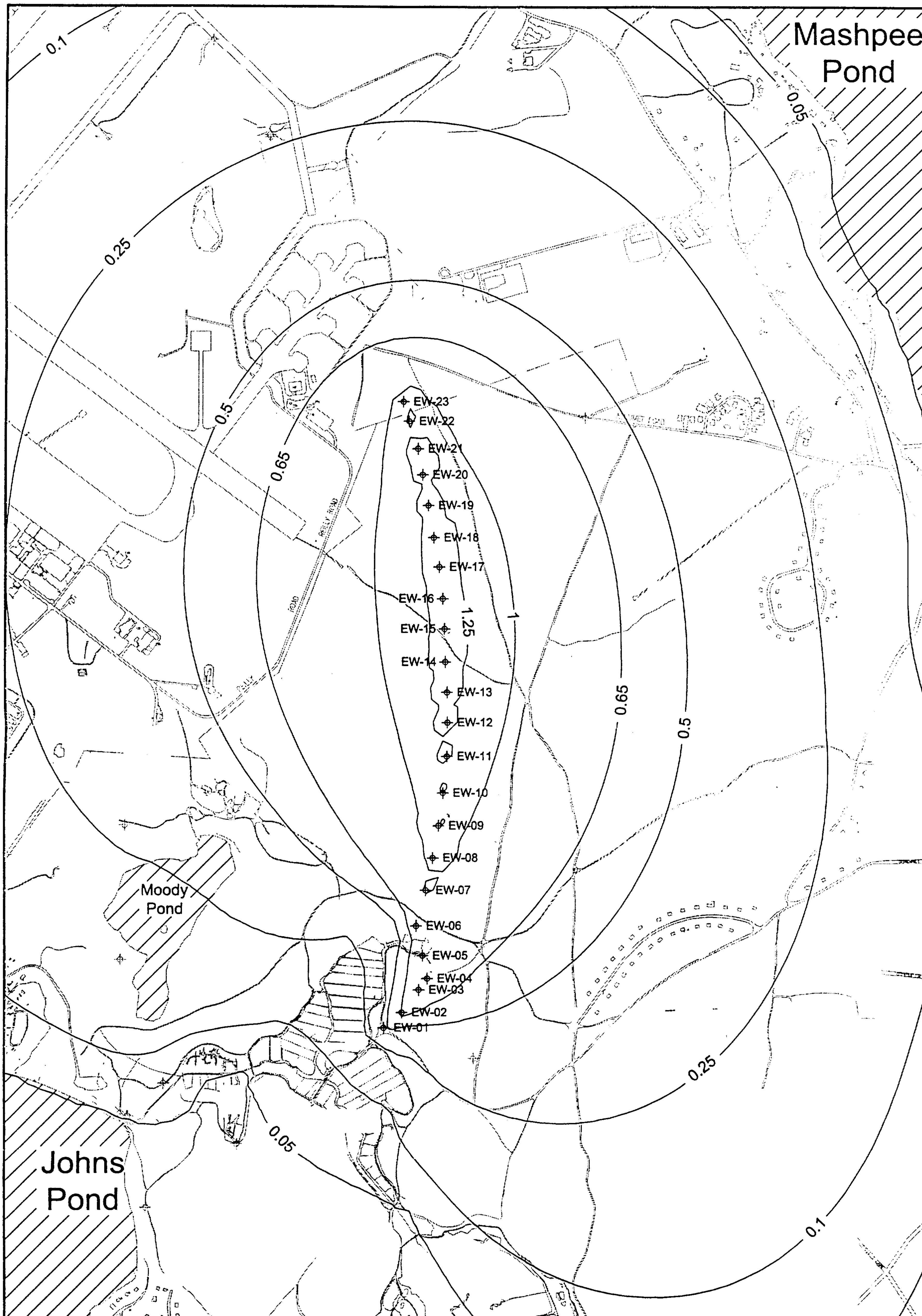


Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: —0.5— Drawdown Contour EW-07 ⊕ — Extraction Well	Scale 0 250 500 1000 North	FS-1 Stage 1 Modeling Run 5 - Well Configuration and Drawdown Massachusetts Military Reservation Drawing Version No.: Rev. 0 Date: 2/4/99 Drawing Name: Drawdown.dwg Figure No. 13



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: Scale 0 250 500 1000 —0.5— Drawdown Contour EW-07 ⊕ — Extraction Well North	FS-1 Stage 1 Modeling Run 6 - Well Configuration and Drawdown Massachusetts Military Reservation Drawing Version No.: Rev. 0 · Date: 2/4/99 · Drawing Name: Drawdown.dwg · Figure No. 14

Figure 14. FS-1 Stage 1 Modeling, Run 6 – Well Configuration and Drawdown



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: Scale 0 250 500 1000 0.5 Drawdown Contour EW-07 — Extraction Well North	FS-1 Stage 1 Modeling Run 7 - Well Configuration and Drawdown Massachusetts Military Reservation Drawing Version No.: Rev. 0 Date: 2/4/99 | Drawing Name: Drawdown.dwg | Figure No. 15

Figure 15. FS-1 Stage 1 Modeling, Run 7 – Well Configuration and Drawdown

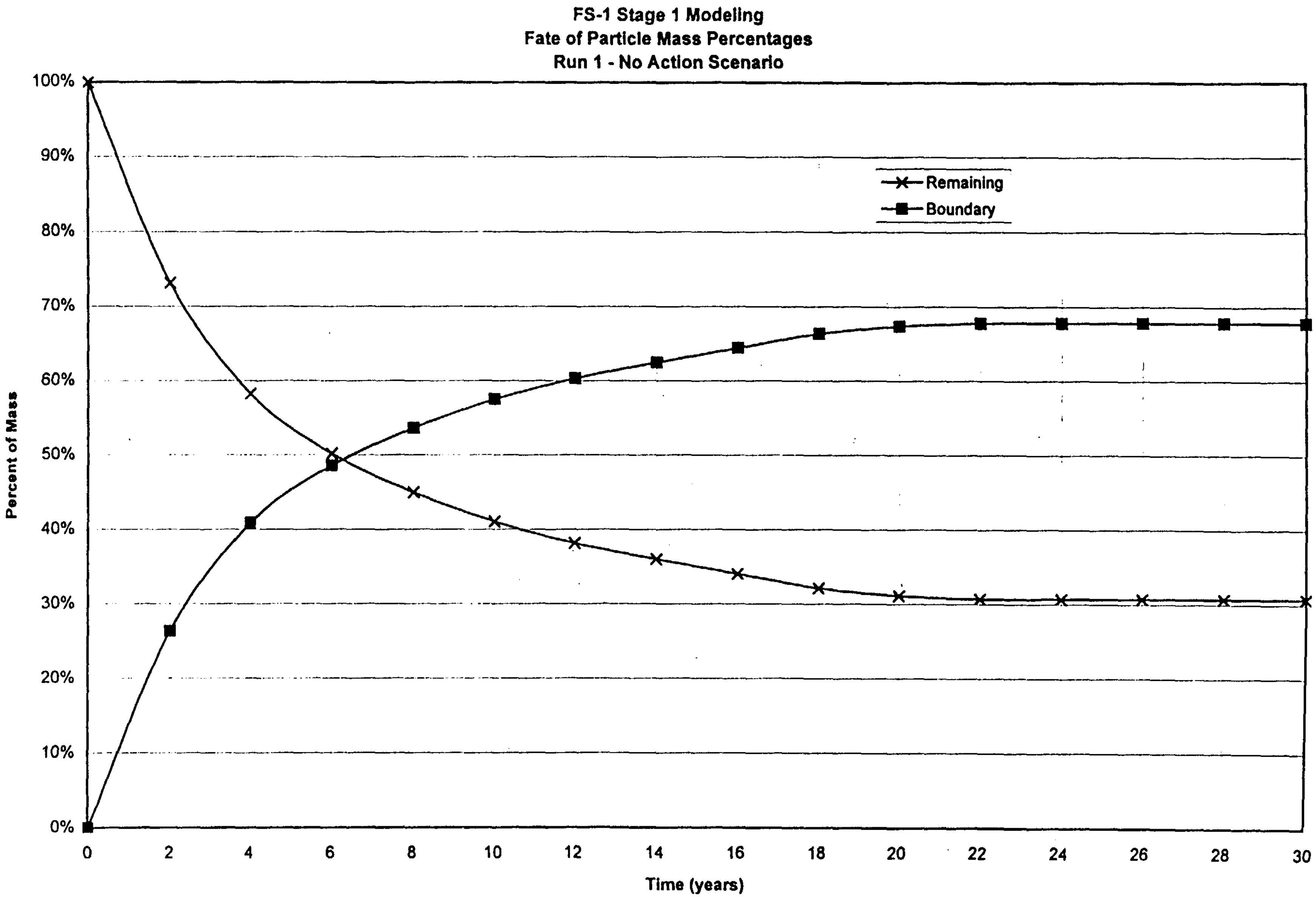


Figure 16. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 1 – No Action Scenario

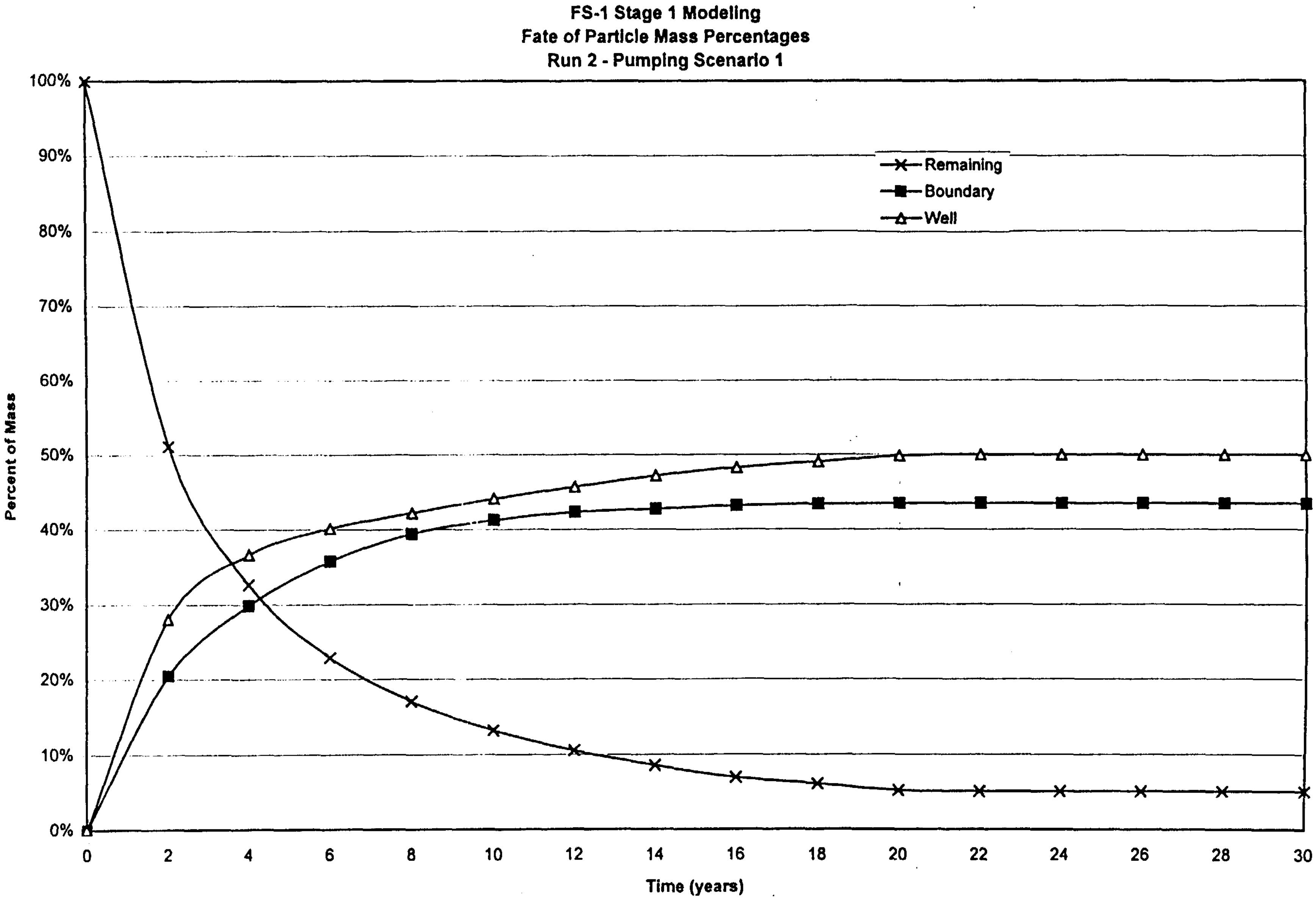


Figure 17. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 2 – Pumping Scenario 1

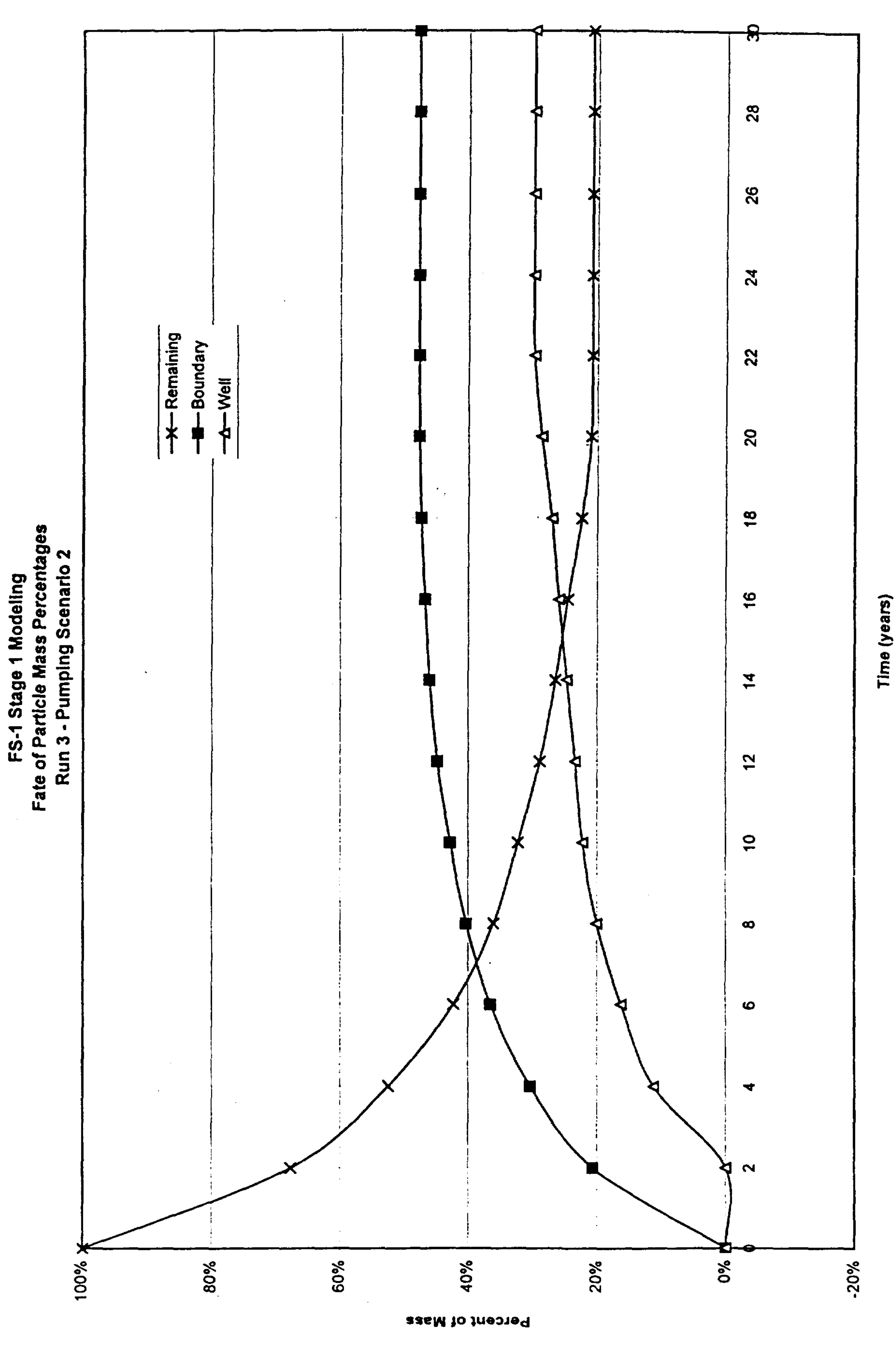


Figure 18. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 3 – Pumping Scenario 2

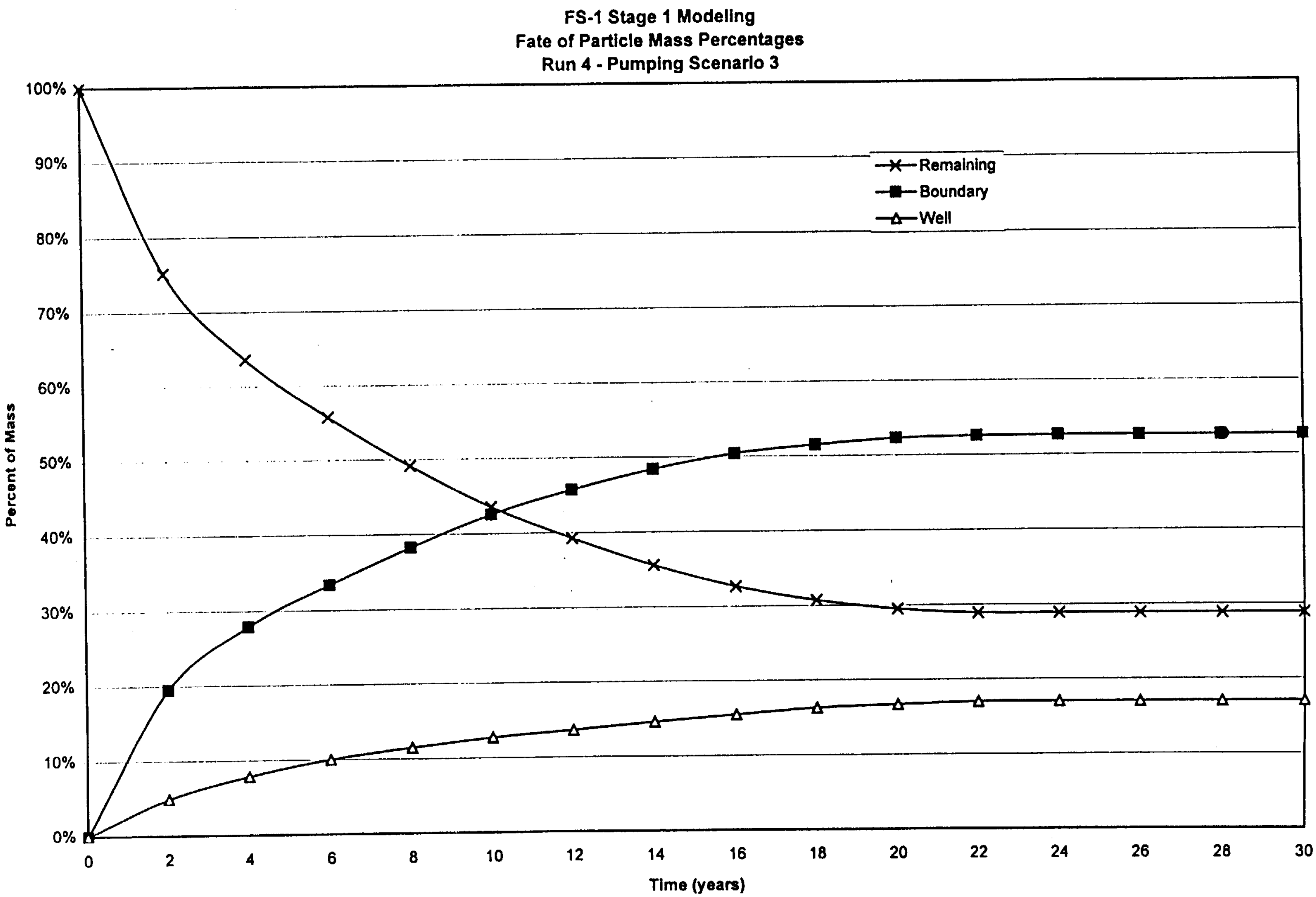


Figure 19. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 4 – Pumping Scenario 3

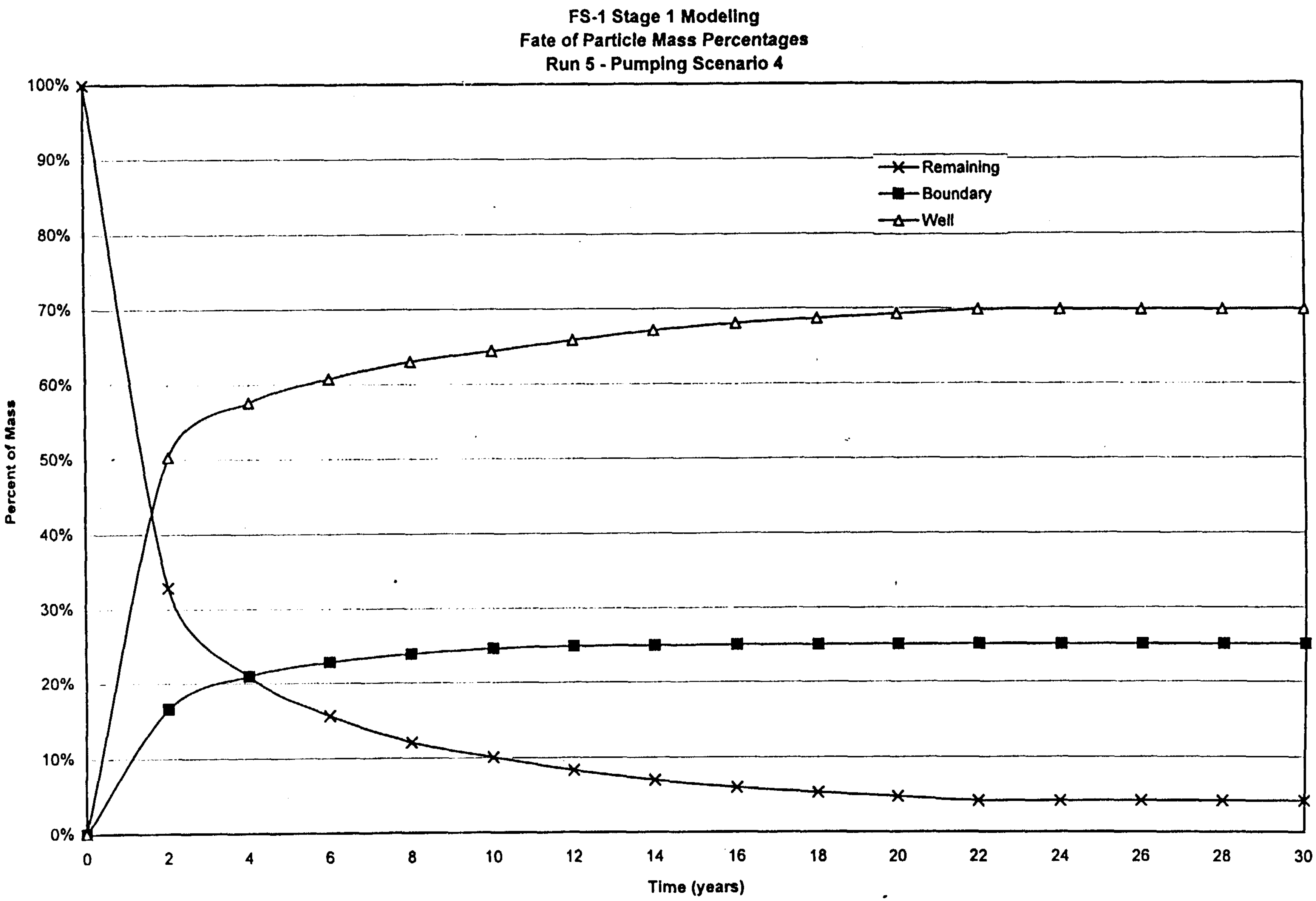


Figure 20. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 5 – Pumping Scenario 4

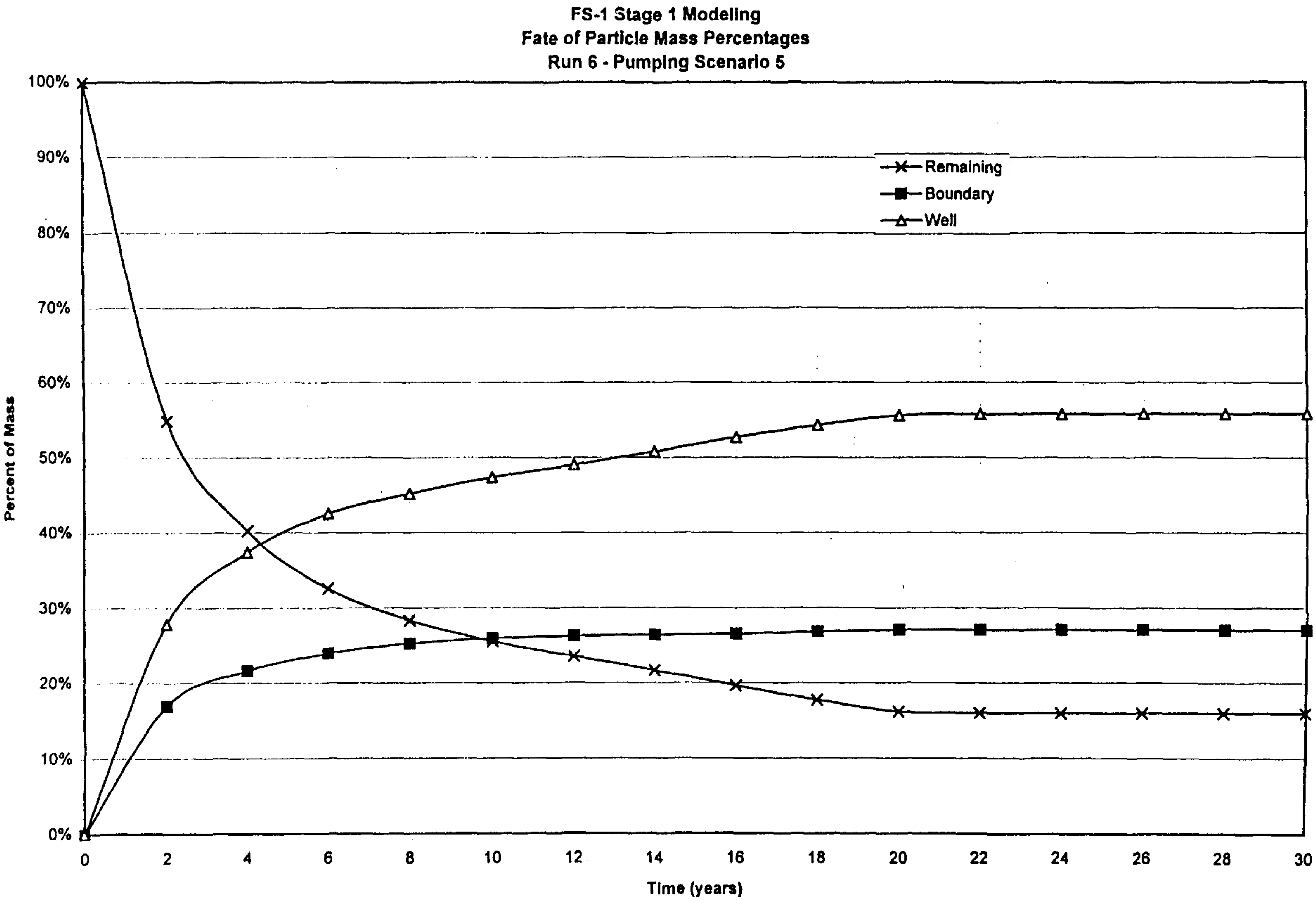


Figure 21. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 6 – Pumping Scenario 5

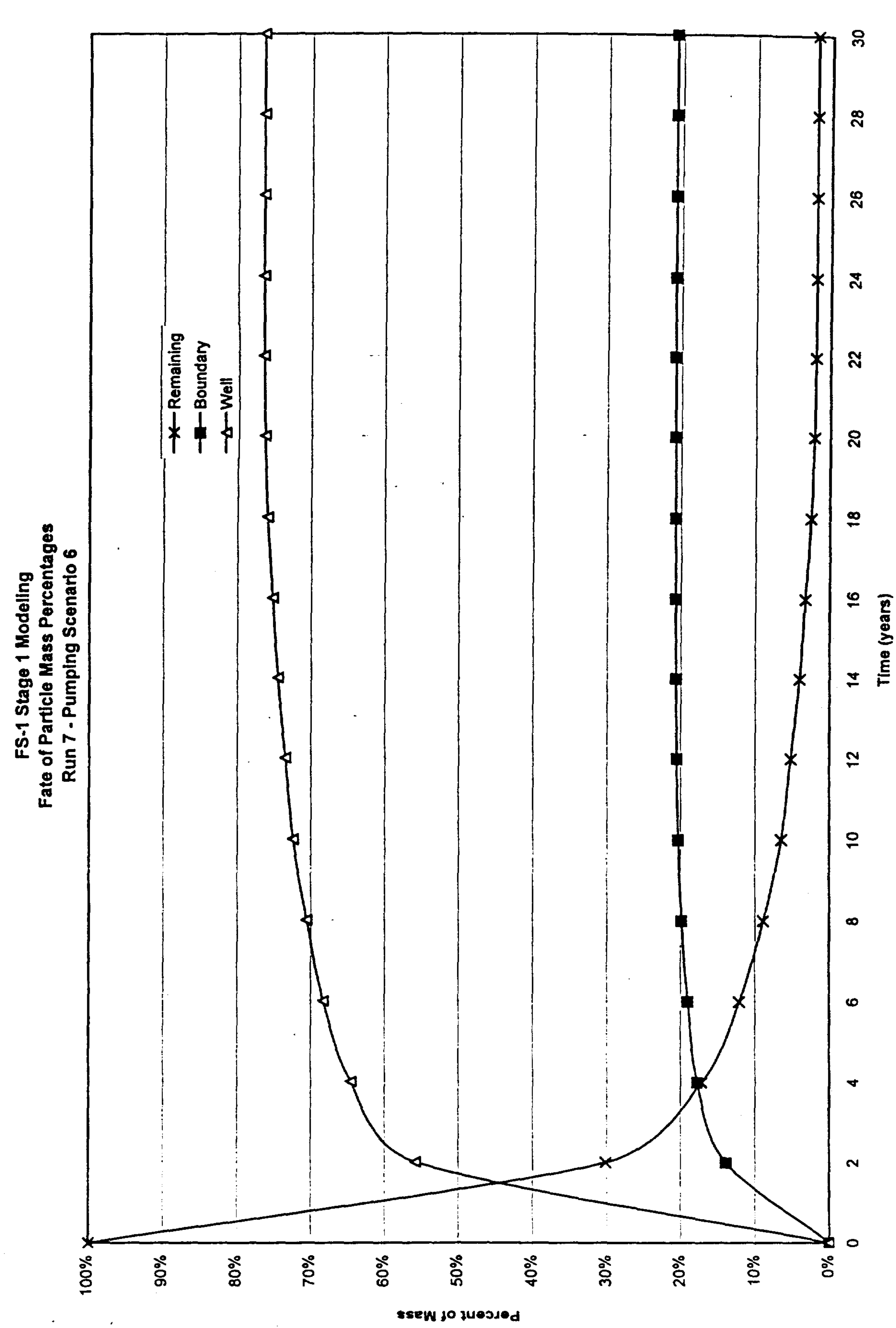


Figure 22. FS-1 Stage 1 Modeling, Fate of Particle Mass Percentages, Run 7 – Pumping Scenario 6

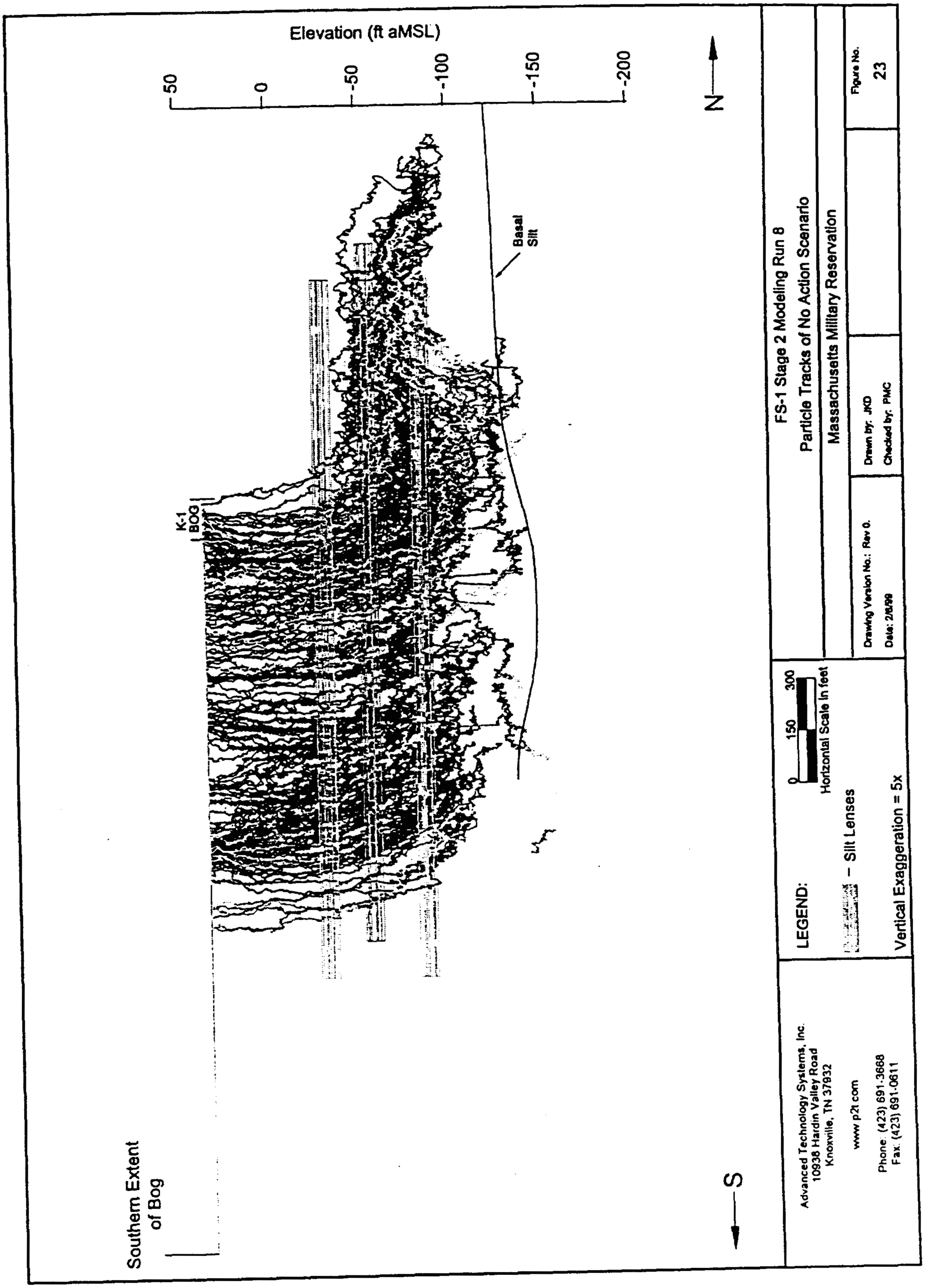


Figure 23. FS-1 Stage 2 Modeling Run 8, Particle Tracks of No Action Scenario

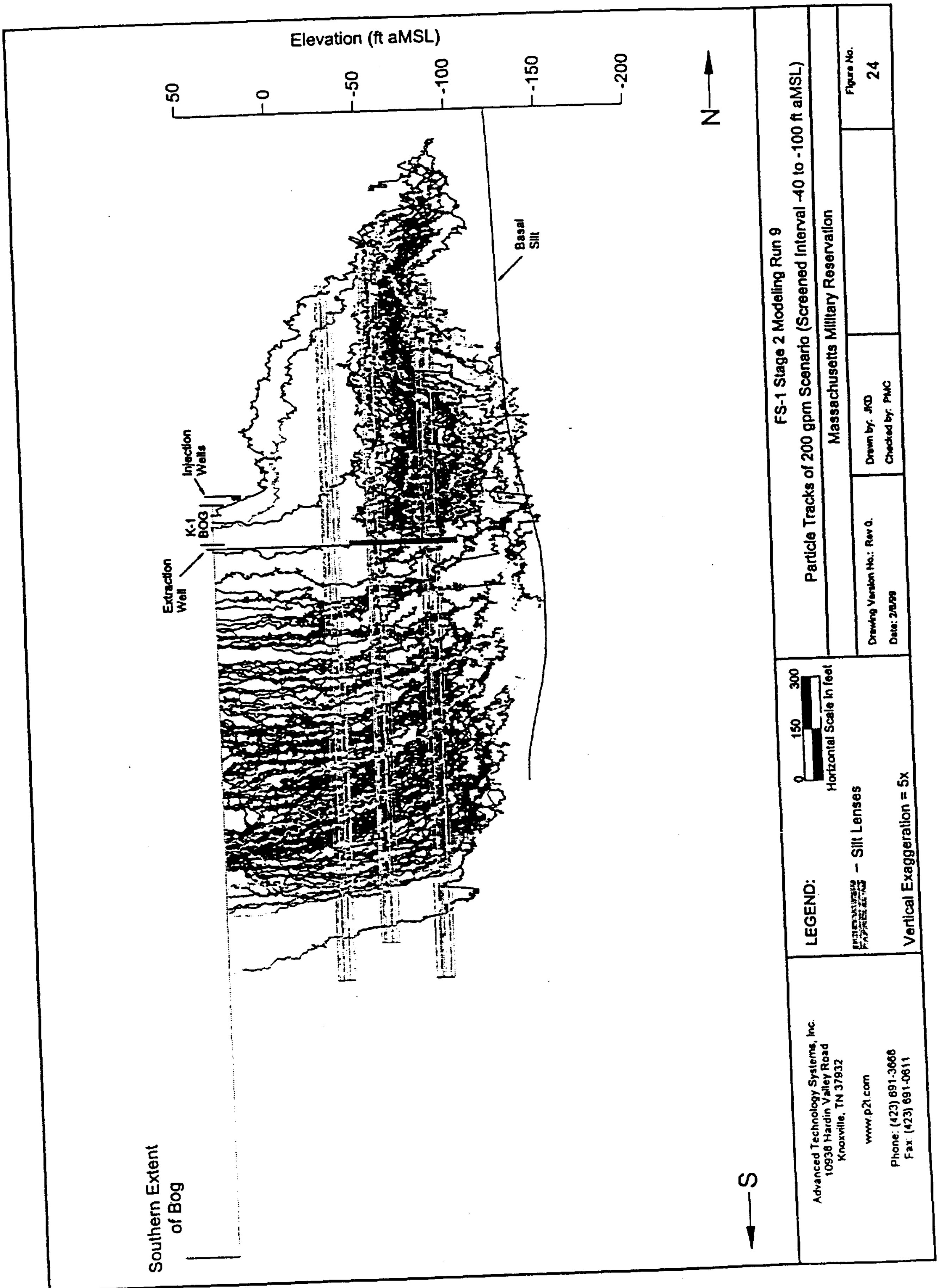


Figure 24. FS-1 Stage 2 Modeling Run 9, Particle Tracks of 200 gpm Scenario (Screened Interval -40 to -100 ft aMSL)

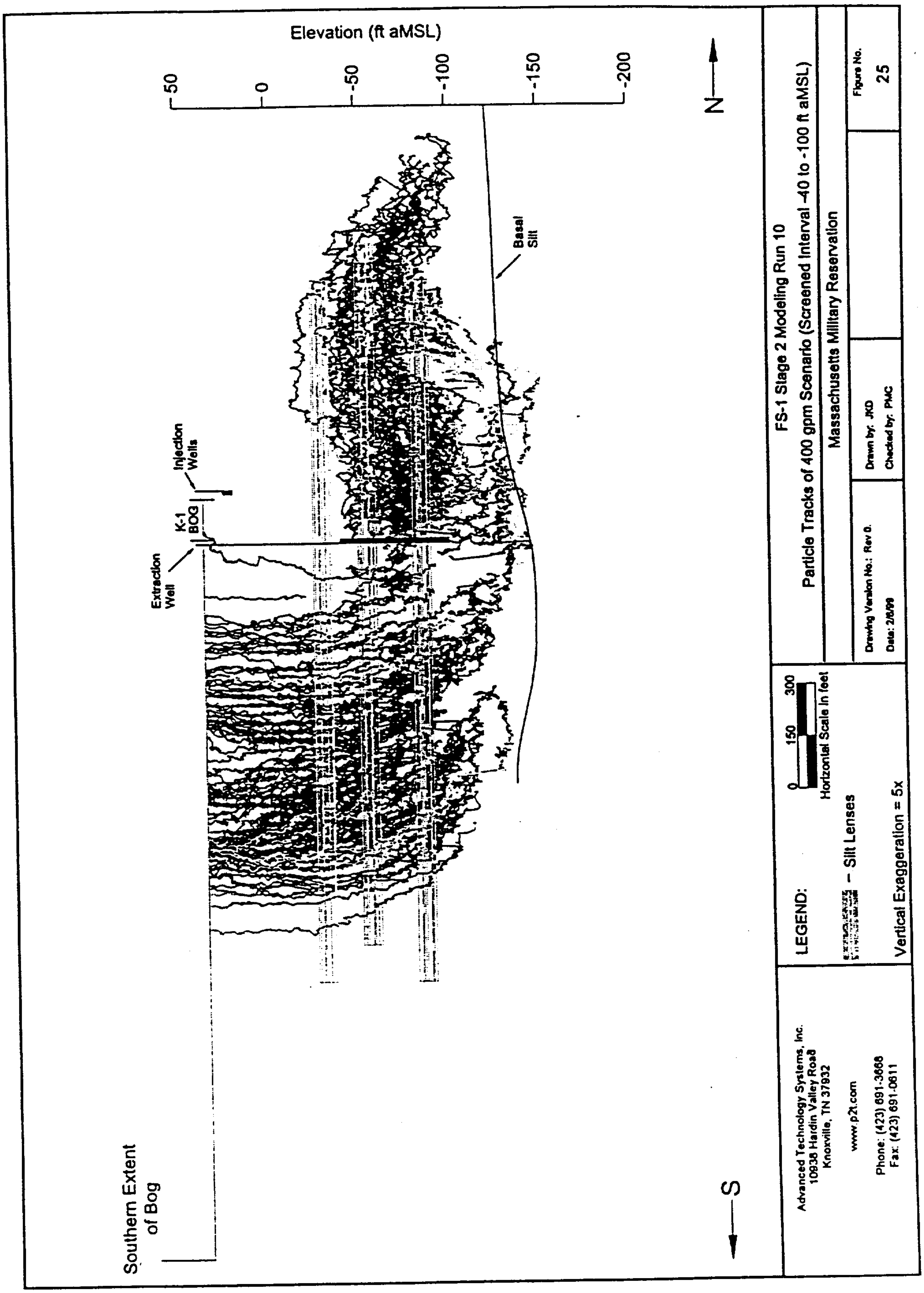


Figure 25. FS-1 Stage 2 Modeling Run 10, Particle Tracks of 400 gpm Scenario (Screened Interval -40 to -100 ft aMSL)

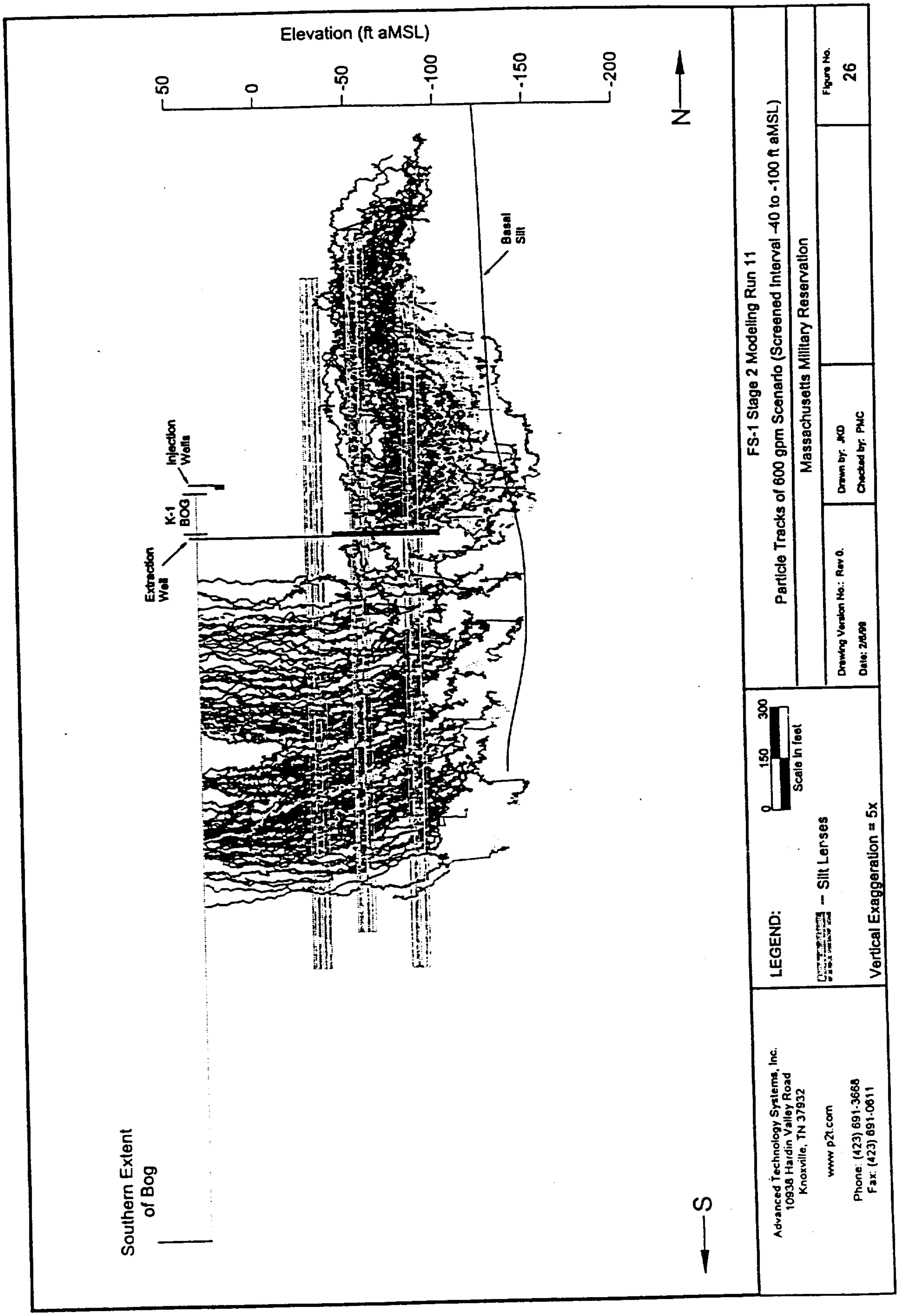
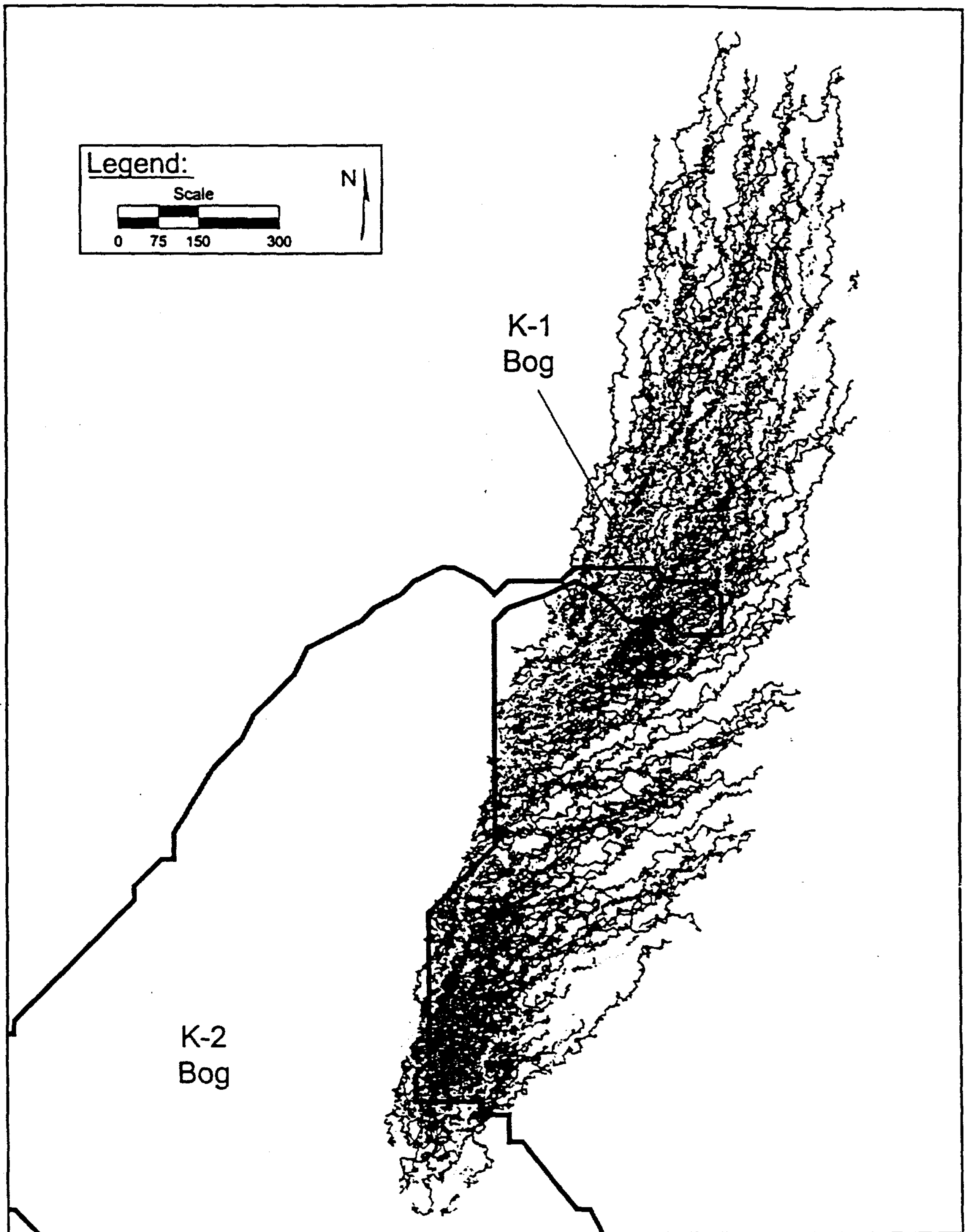


Figure 26. FS-1 Stage 2 Modeling Run 11, Particle Tracks of 600 gpm Scenario (Screened Interval -40 to -100 ft aMSL)



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	Drawing Version No.: Rev. 0 Date: 2/6/99	Drawn by: JKD Checked by: PMC		Figure No. 27

Figure 27. FS-1 Stage 2 Modeling Run 8, Particle Tracks of No Action Scenario

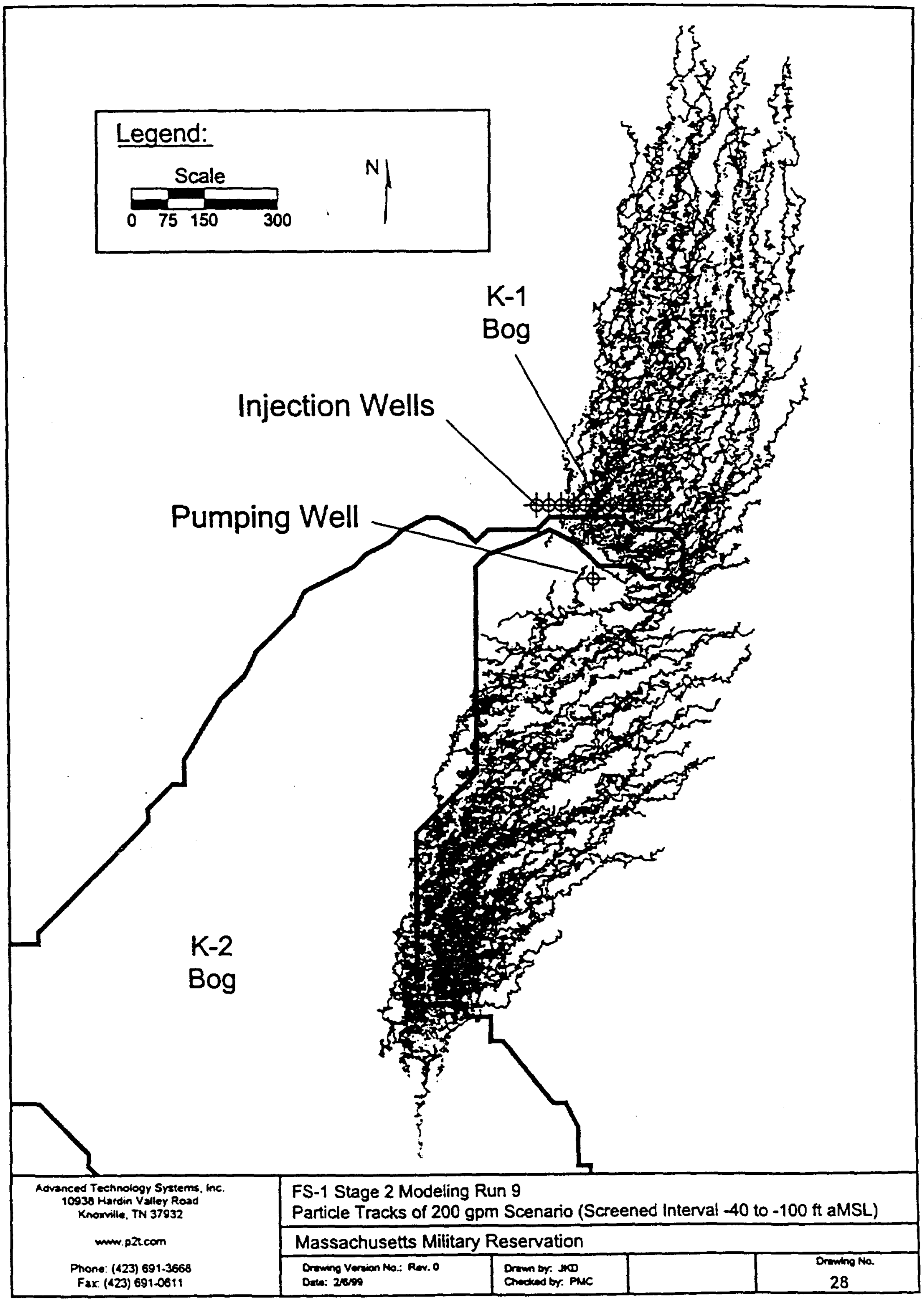
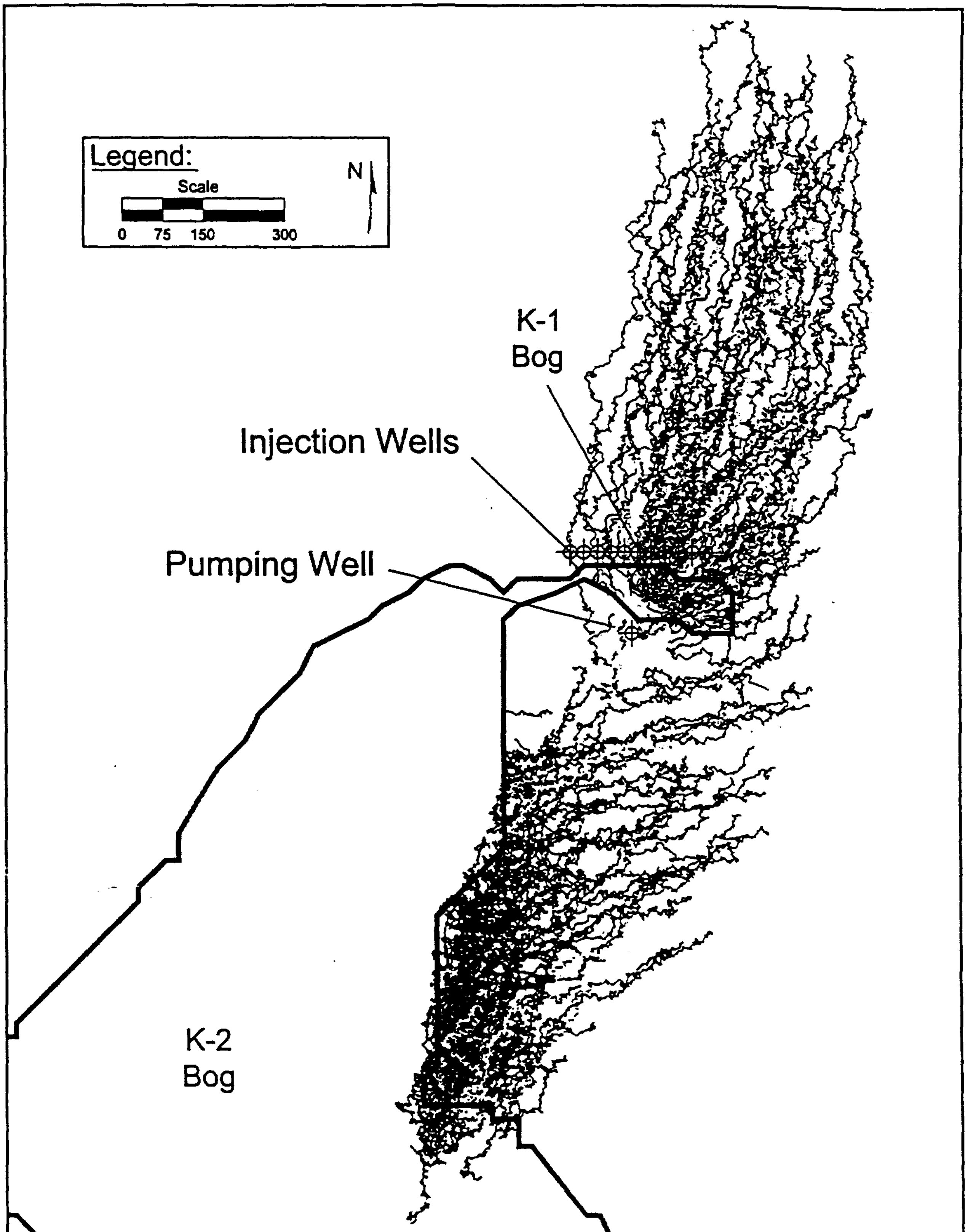


Figure 28. FS-1 Stage 2 Modeling Run 9, Particle Tracks of 200 gpm Scenario (Screened Interval -40 to -100 ft aMSL)



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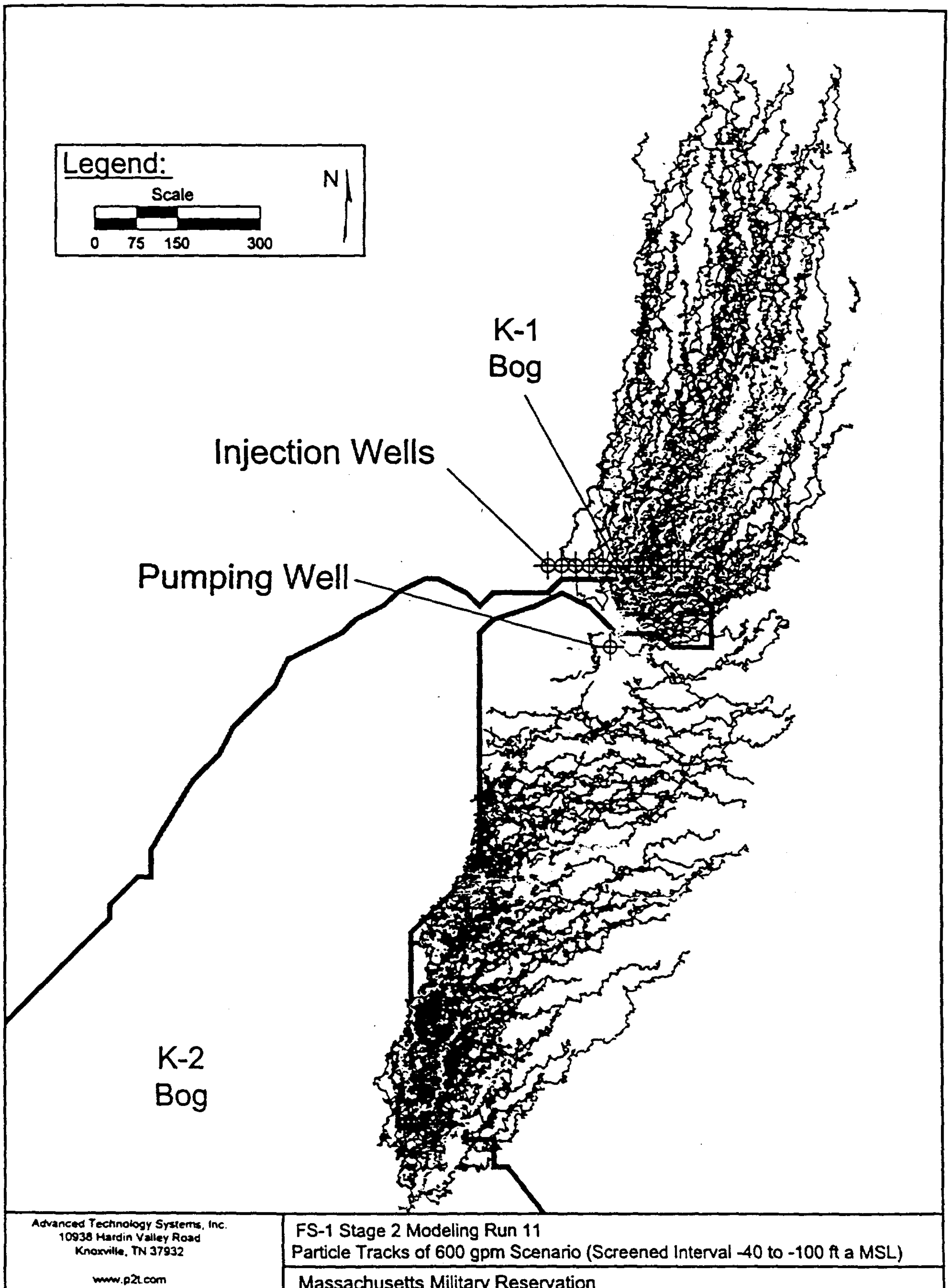
www.p2t.com	Massachusetts Military Reservation			
Phone: (423) 691-3668 Fax: (423) 691-0611	Drawing Version No.: Rev. 0 Date: 2/6/99	Drawn by: JKD Checked by: PMC		Drawing No. 29

Figure 29. FS-1 Stage 2 Modeling Run 10, Particle Tracks of 400 gpm Scenario (Screened Interval -40 to -100 ft aMSL)



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	FS-1 Stage 2 Modeling Run 11 Particle Tracks of 600 gpm Scenario (Screened Interval -40 to -100 ft a MSL)			
	Massachusetts Military Reservation			
	Drawing Version No.: Rev. 0 Date: 2/6/99	Drawn by: JKD Checked by: PMC		Figure No. 30

Figure 30. FS-1 Stage 2 Modeling Run 11, Particle Tracks of 600 gpm Scenario (Screened Interval -40 to -100 ft aMSL)

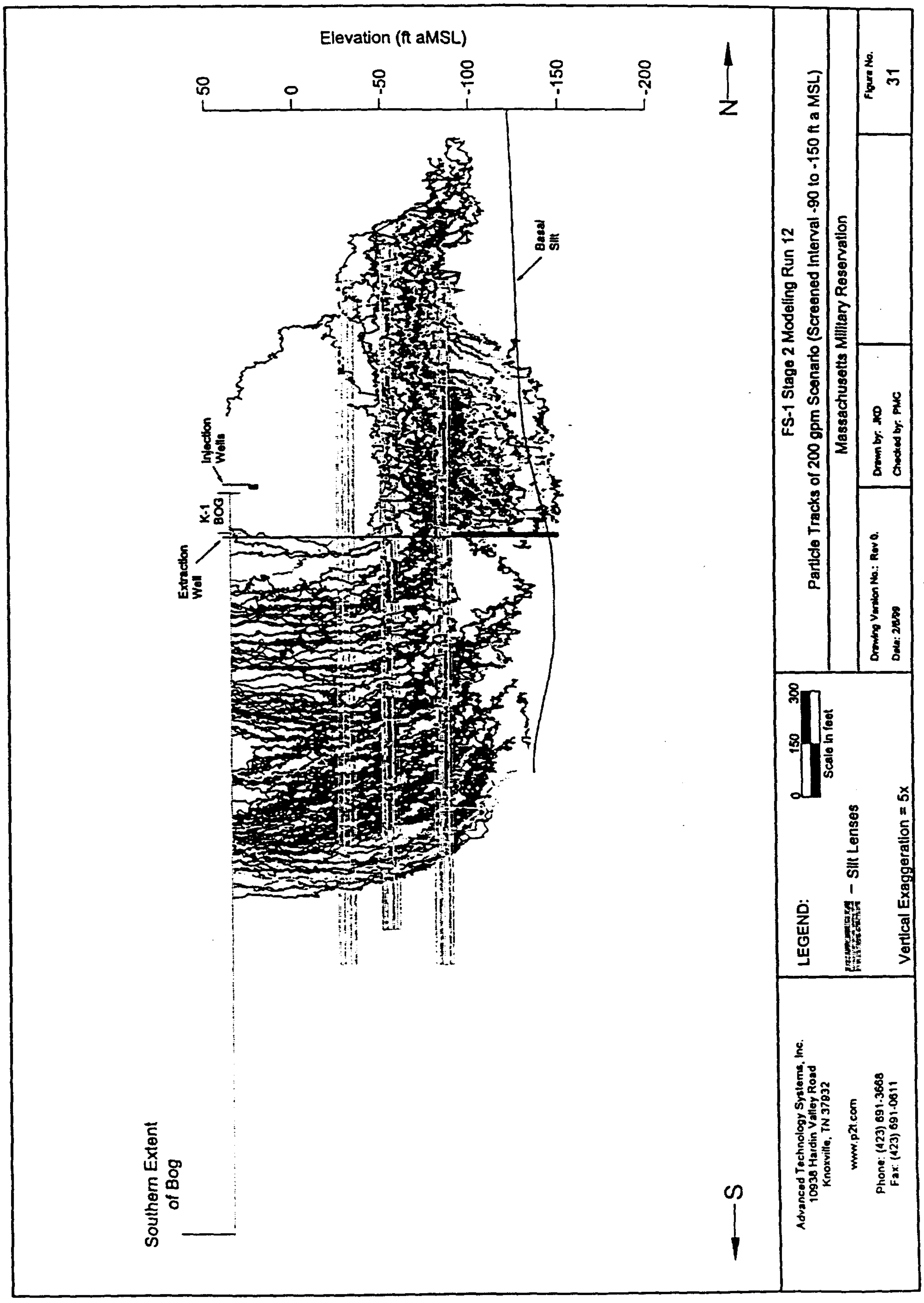
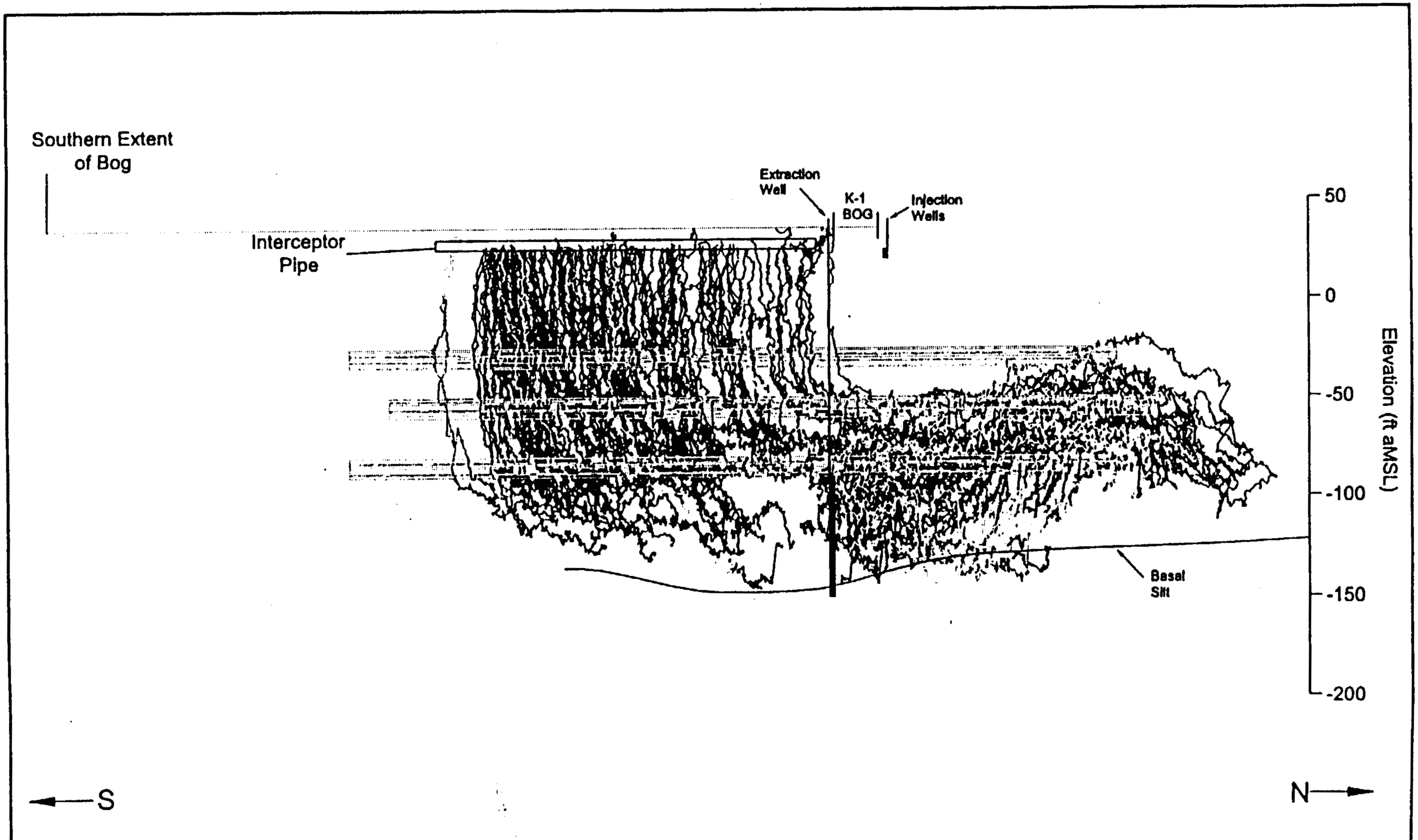


Figure 31. FS-1 Stage 2 Modeling Run 12, Particle Tracks of 200 gpm Scenario (Screened Interval -90 to -150 ft aMSL)



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LEGEND:

0 150 300
Horizontal Scale in feet

– Silt Lenses

Vertical Exaggeration = 5x

FS-1 Stage 2 Modeling Run 13
Particle Tracks of 200 gpm Scenario (Screened Interval -90 to -150 ft aMSL)
with Interceptor Pipe 10 ft Below Water Table and pumped at 300 gpm

Massachusetts Military Reservation

Drawing Version No.: Rev 0. Date: 1/25/99	Drawn by: JKD Checked by: PMC		Figure No. 32

Figure 32. FS-1 Stage 2 Modeling Run 13, Particle Tracks of 200 gpm Scenario (Screened Interval -90 to -150 ft aMSL) with Interceptor Pipe 10 ft Below Water Table and Pumped at 300 gpm

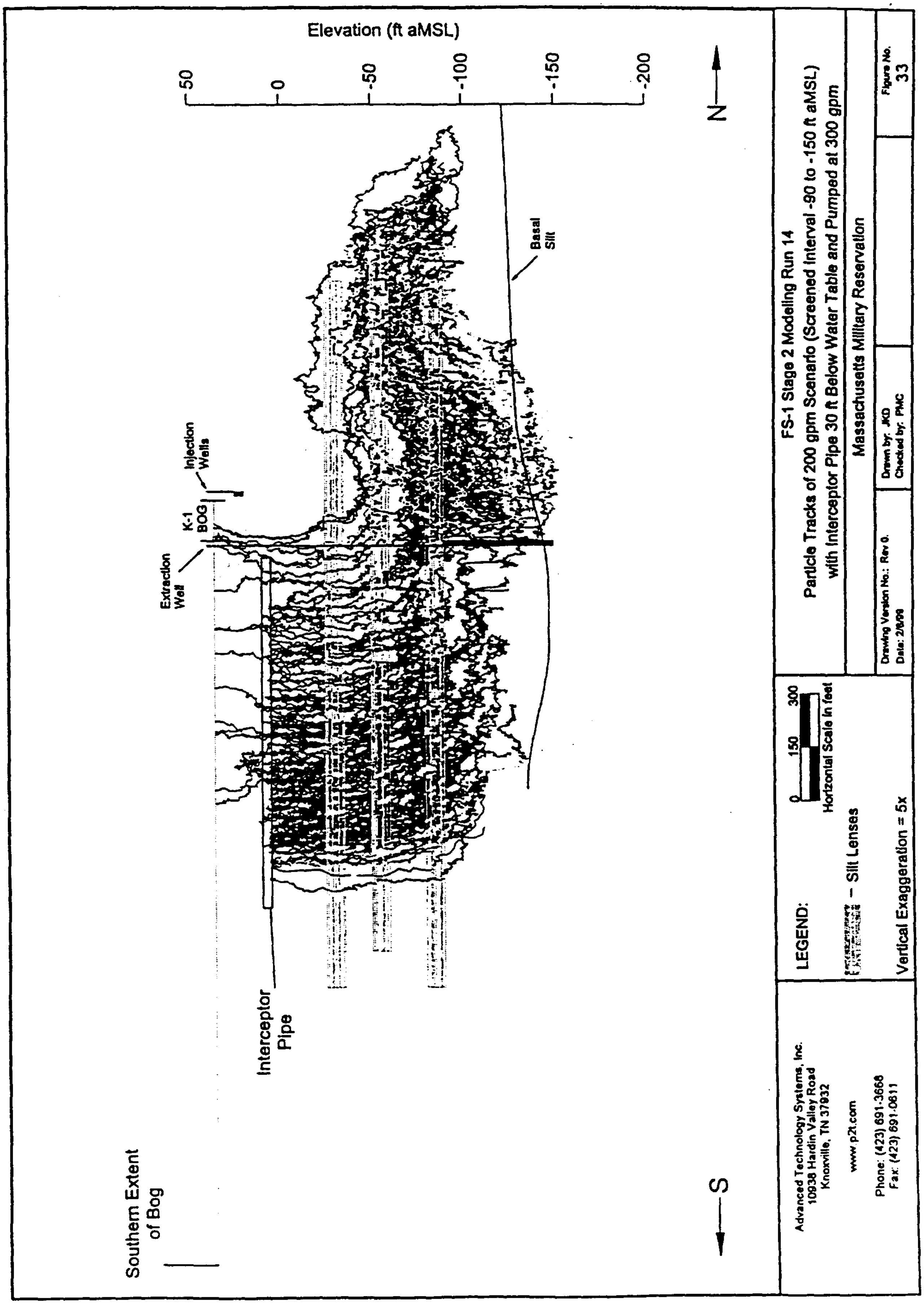
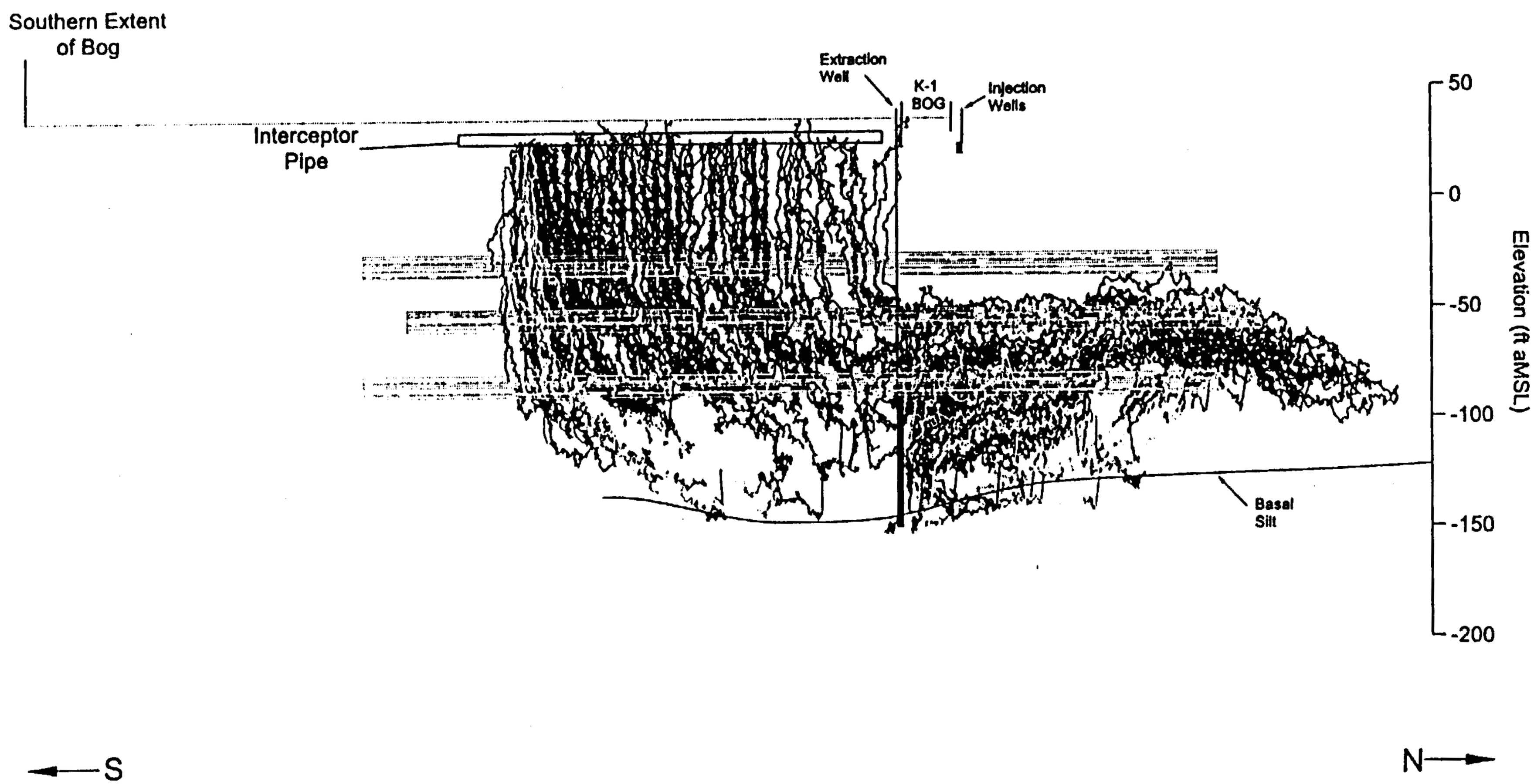


Figure 33. FS-1 Stage 2 Modeling Run 14, Particle Tracks of 200 gpm Scenario (Srceened Interval -90 to -150 ft aMSL) with Interceptor Pipe 30 ft Below Water Table and Pumped at 300 gpm



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LEGEND:

0 150 300
Horizontal Scale in feet

– Silt Lenses

Vertical Exaggeration = 5x

FS-1 Stage 2 Modeling Run 15
Particle Tracks of 200 gpm Scenario (Screened Interval -90 to -150 ft aMSL)
with Interceptor Pipe 10 ft Below Water Table and Pumped at 400 gpm

Massachusetts Military Reservation

Drawing Version No.: Rev 0. Date: 2/6/99	Drawn by: JKD Checked by: PMC		Figure No. 34

Figure 34. FS-1 Stage 2 Modeling Run 15, Particle Tracks of 200 gpm Scenario (Screened Interval -90 to -150 ft aMSL), with Interceptor Pipe 10 ft Below Water Table and Pumped at 400 gpm

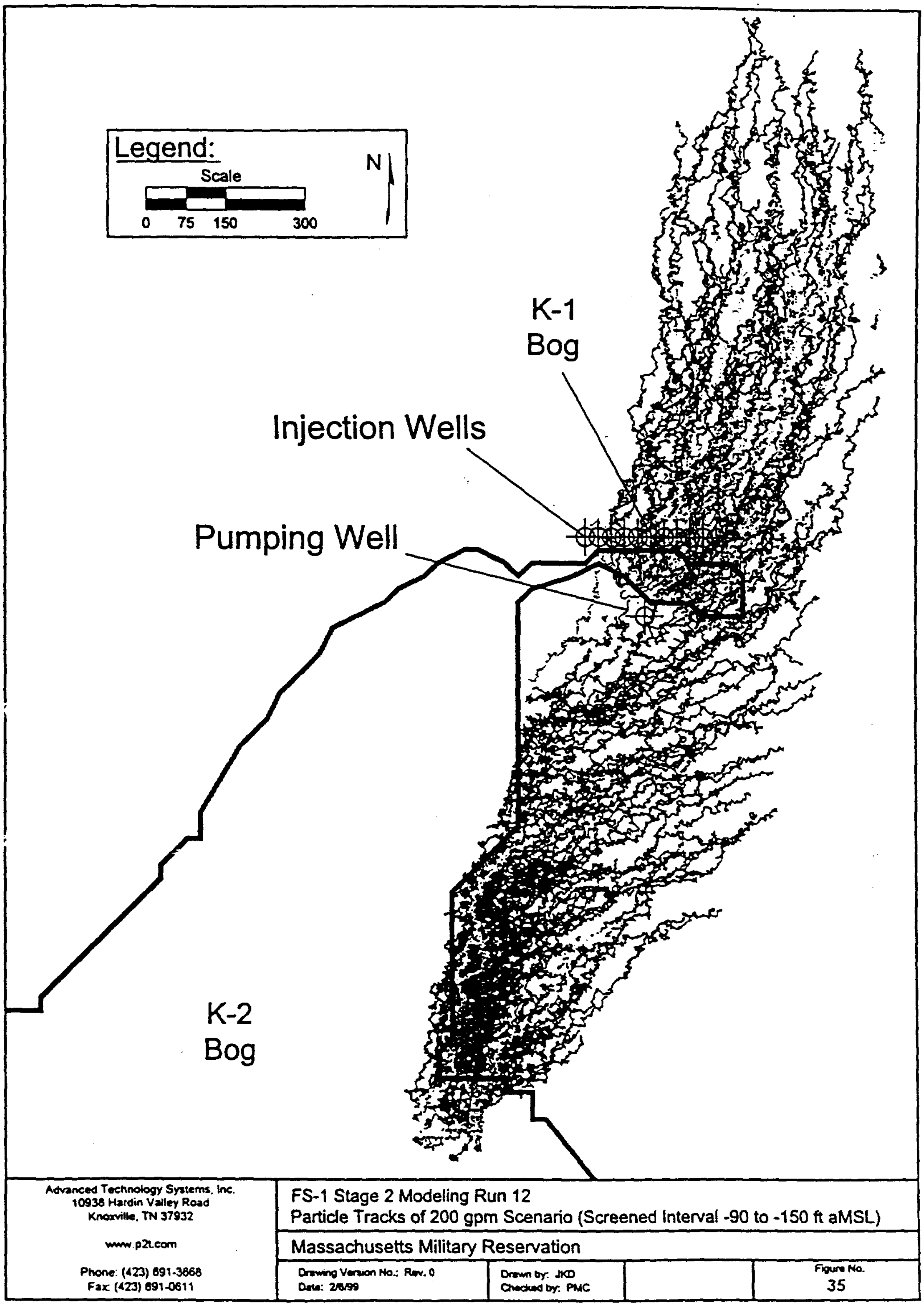
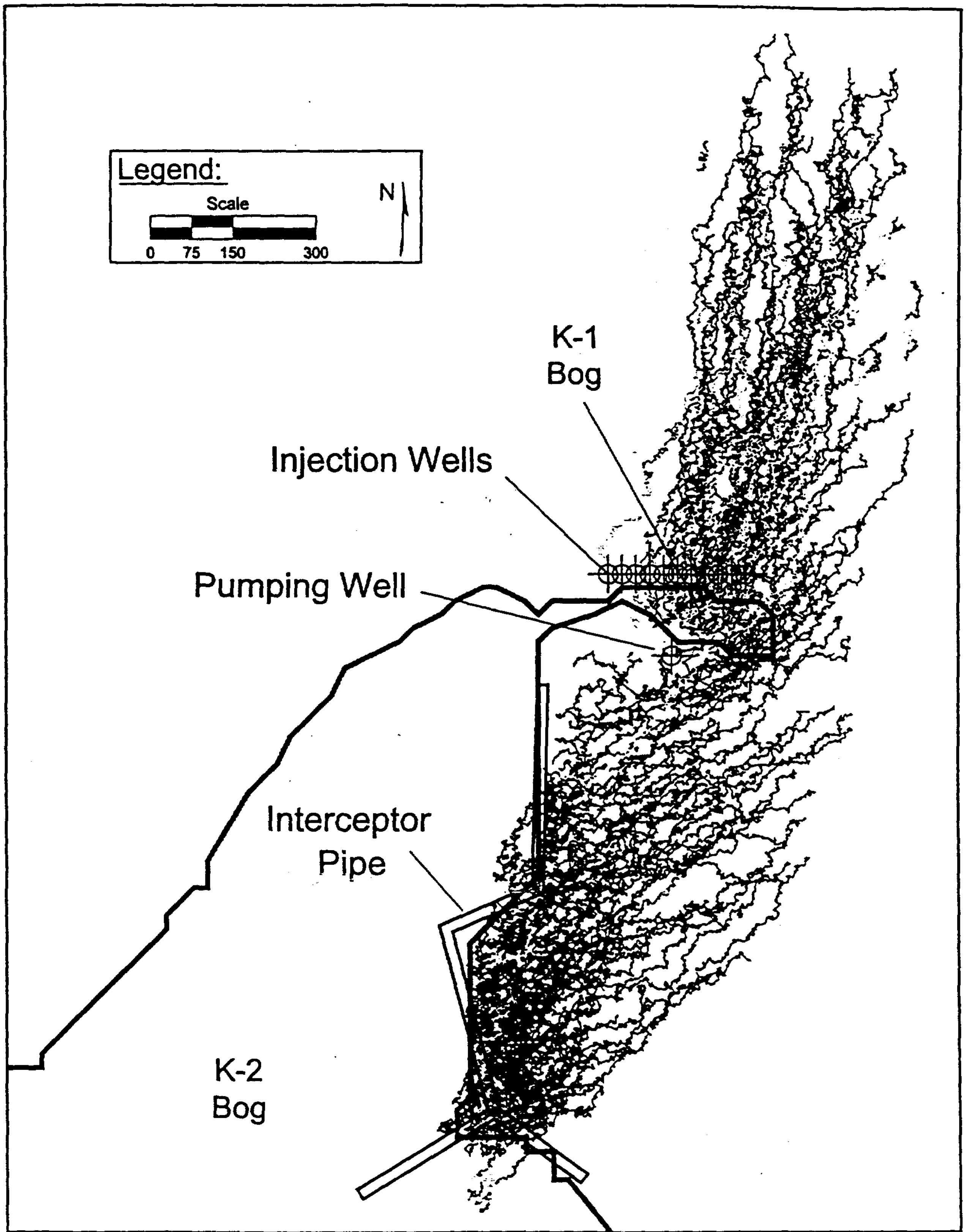
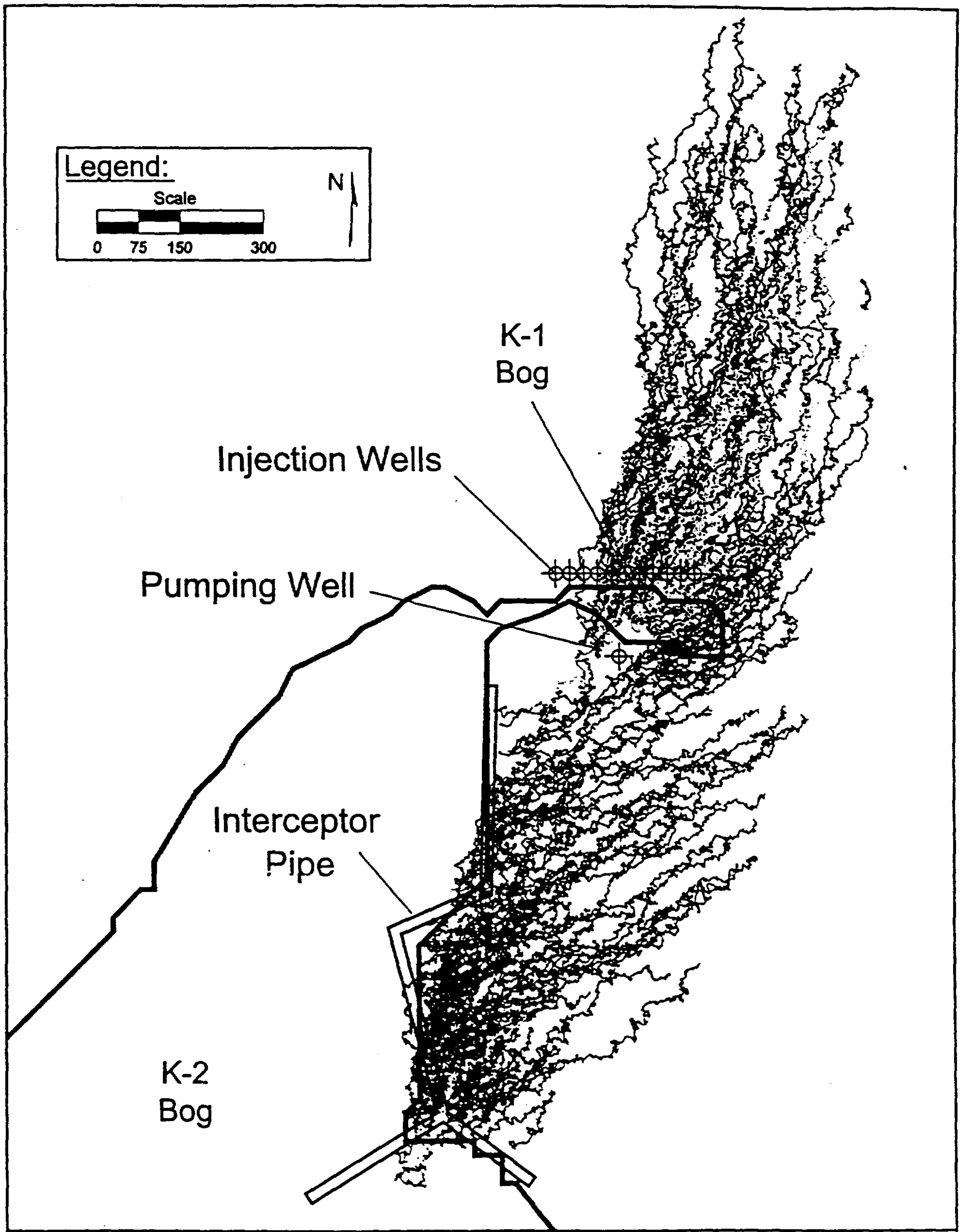


Figure 35. FS-1 Stage 2 Modeling Run 12, Particle Tracks of 200 gpm Scenario (Screened Interval -90 to-150 ft aMSL)



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	FS-1 Stage 2 Modeling Run 13 - Particle Tracks of 200 gpm Scenario with Interceptor Pipe 10 ft Below Water Table and Pumped at 300 gpm			
	Massachusetts Military Reservation			
	Drawing Version No.: Rev. 0 Date: 2/8/99	Drawn by: JKD Checked by: PMC		Figure No. 36

Figure 36. FS-1 Stage 2 Modeling Run 13, Particle Tracks of 200 gpm Scenario with Interceptor Pipe 10 ft Below Water Table and Pumped at 300 gpm



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	FS-1 Stage 2 Modeling Run 14 - Particle Tracks of 200 gpm Scenario with Interceptor Pipe 30 ft Below Water Table and Pumped at 300 gpm Massachusetts Military Reservation			
	Drawing Version No.: Rev. 0 Date: 2/6/99	Drawn by: JKD Checked by: PMC		Figure No. 37

Figure 37. FS-1 Stage 2 Modeling Run 14, Particle Tracks of 200 gpm Scenario with Interceptor Pipe 30 ft Below Water Table and Pumped at 300 gpm

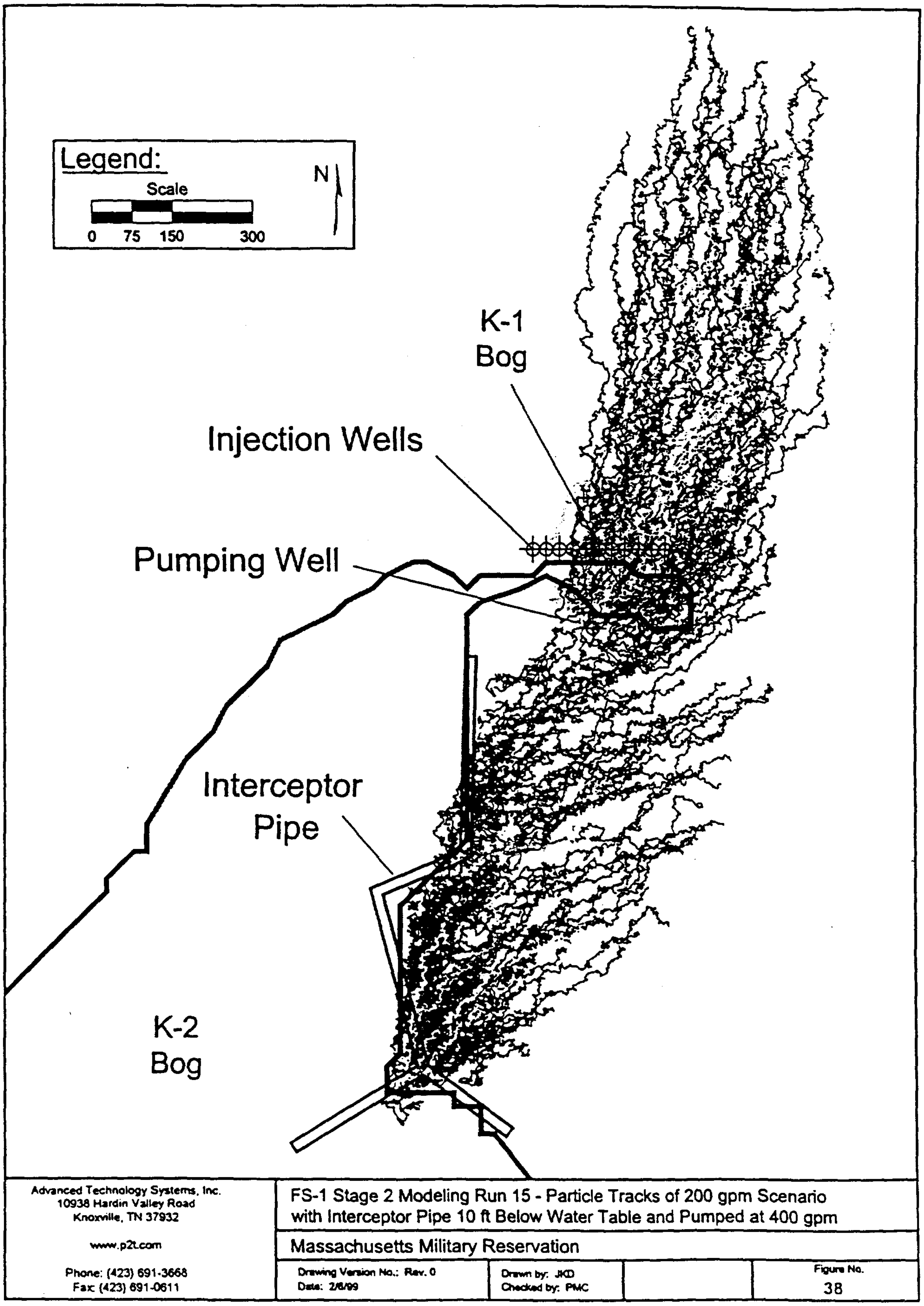


Figure 38. FS-1 Stage 2 Modeling Run 15, Particle Tracks of 200 gpm Scenario with Interceptor Pipe 10 ft Below Water Table and Pumped at 400 gpm

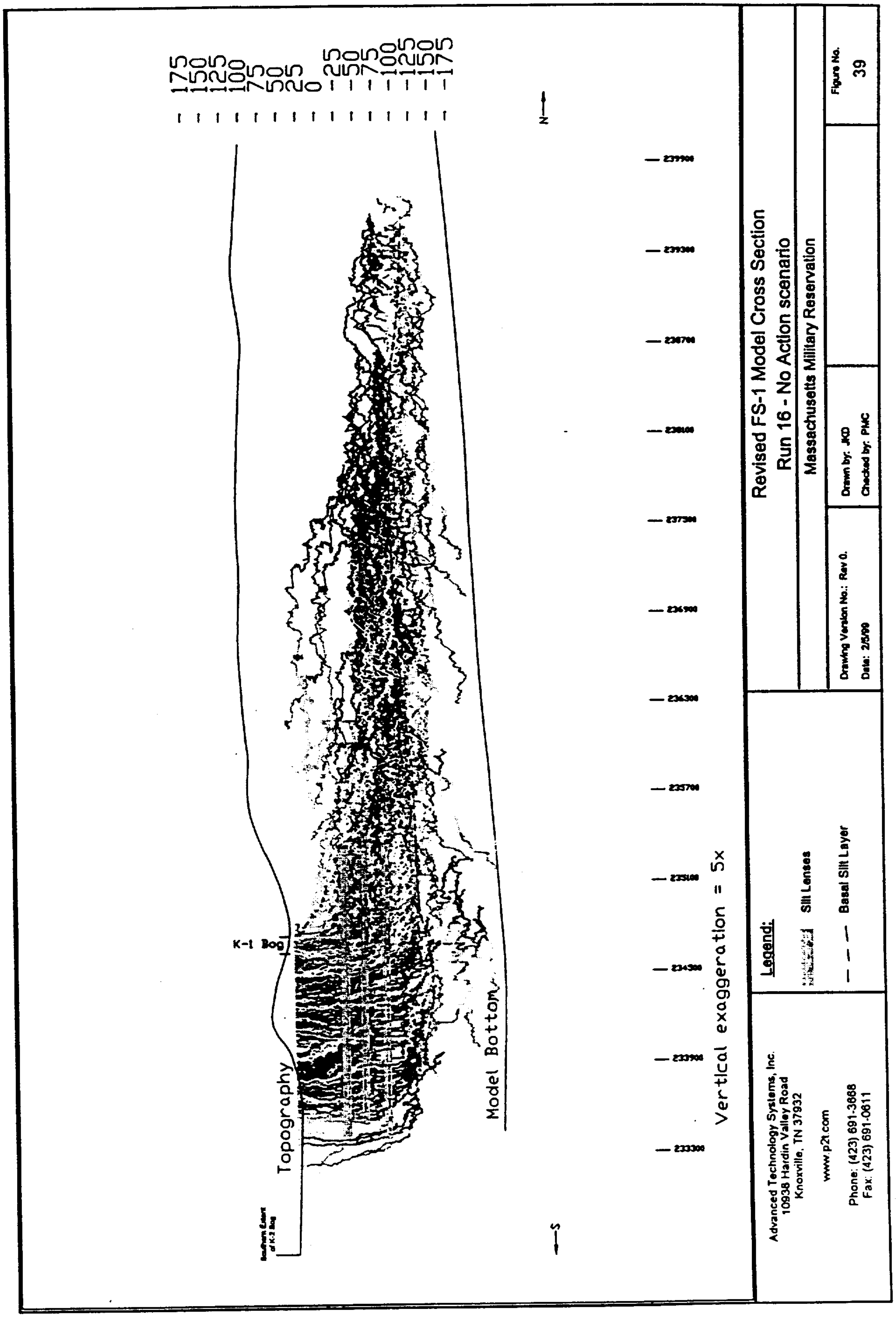


Figure 39. Revised FS-1 Model Cross Section, Run 16 – No Action Scenario

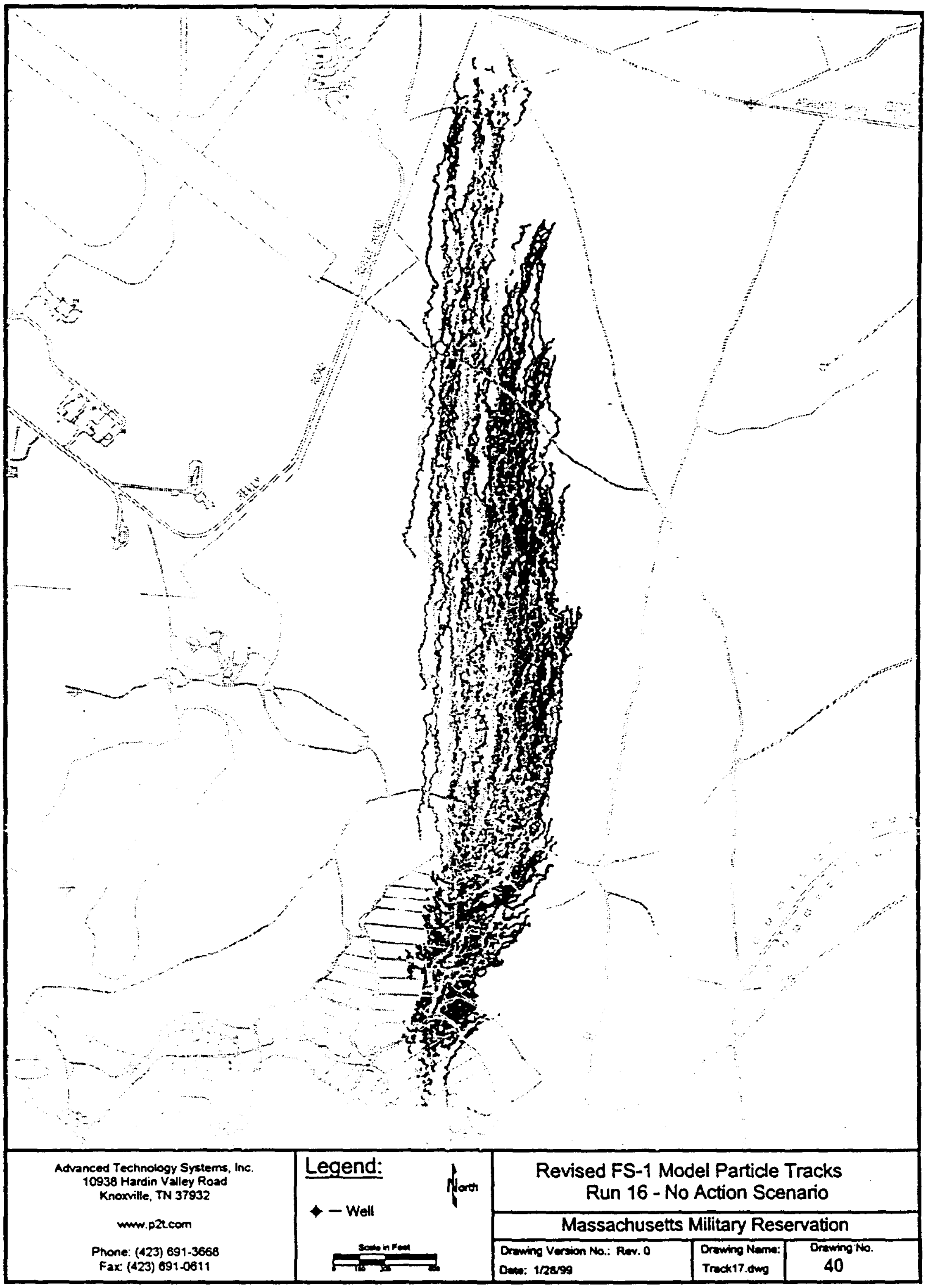


Figure 40. Revised FS-1 Model Particle Tracks, Run 16 – No Action Scenario

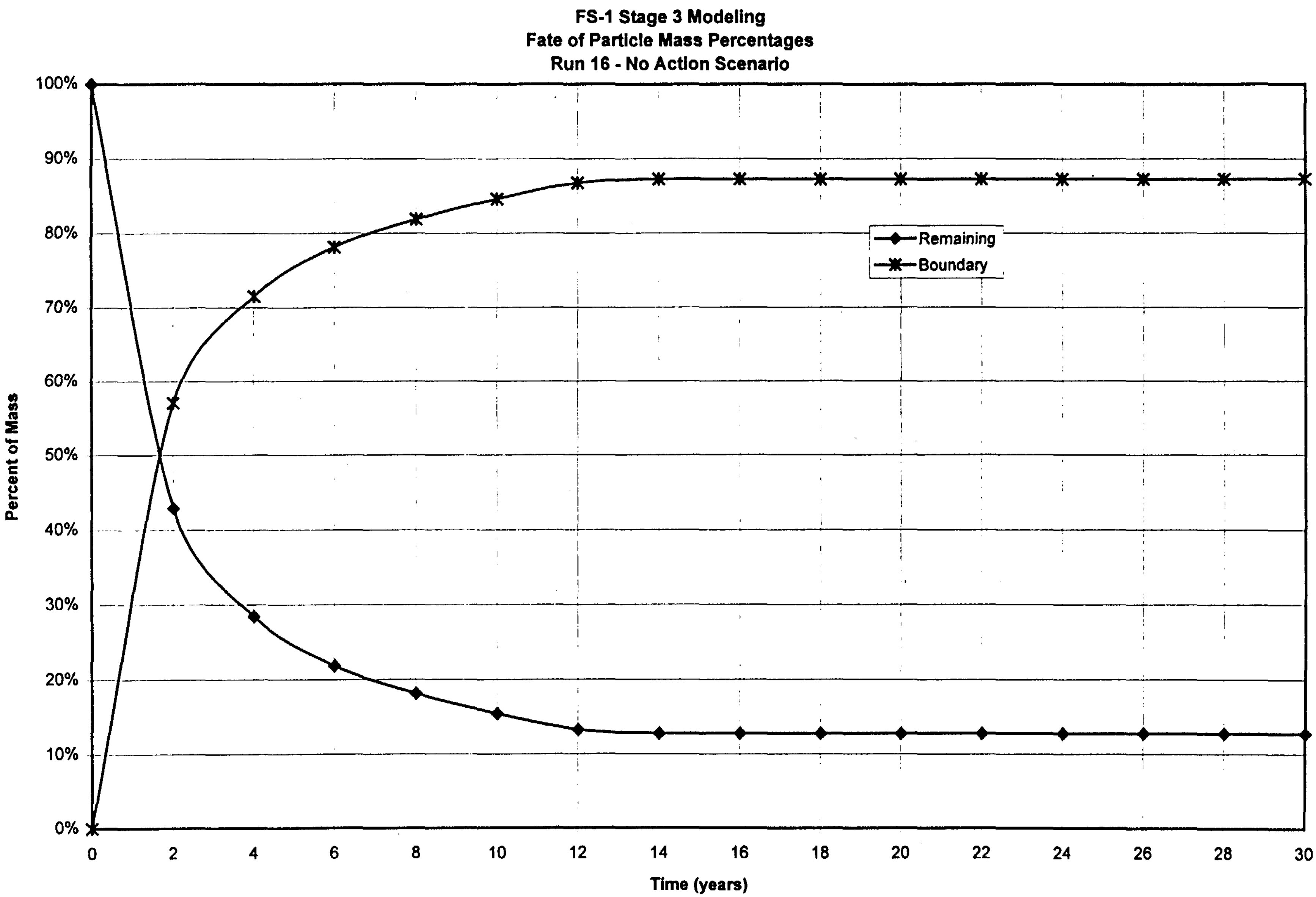
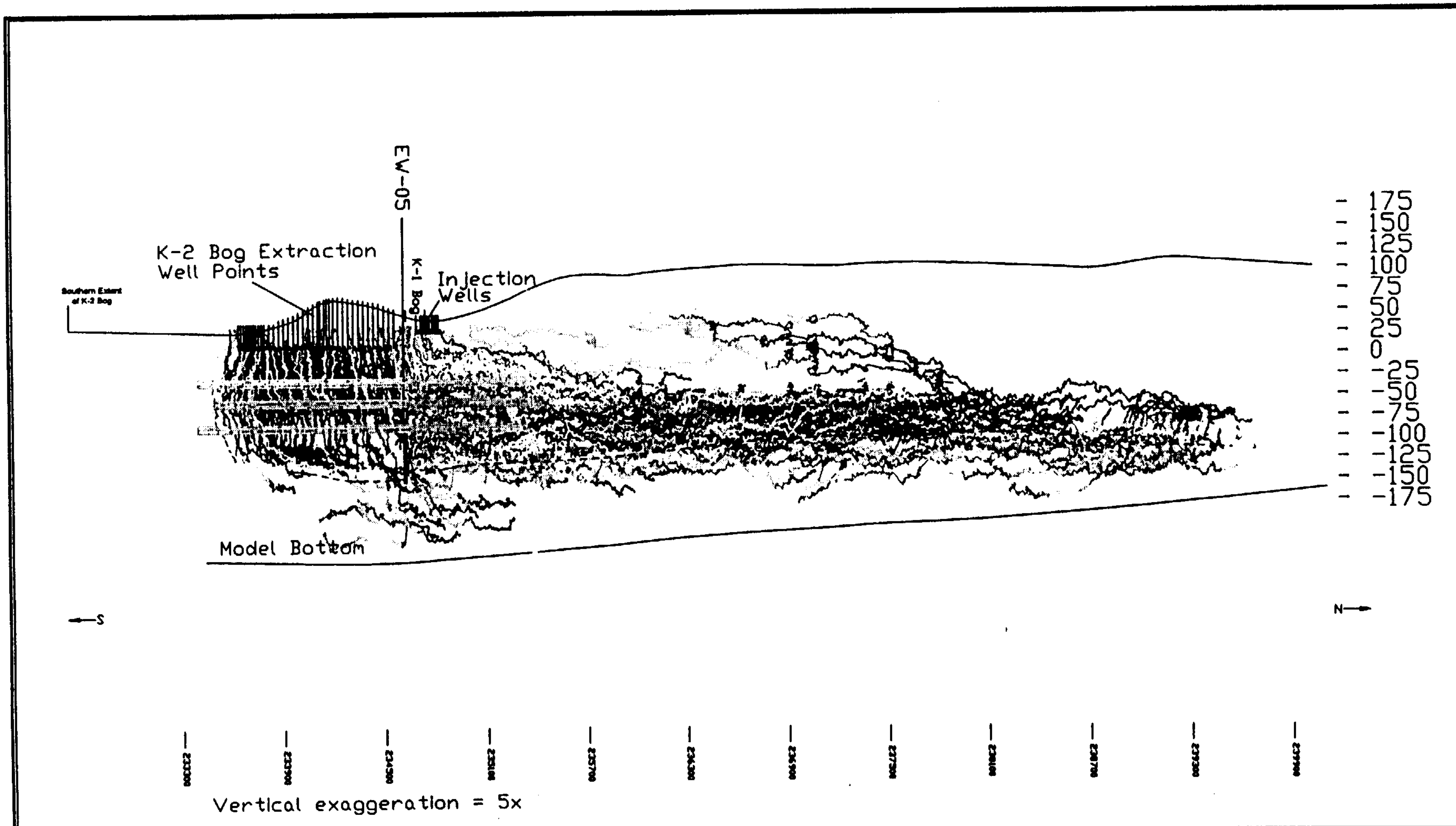


Figure 41. FS-1 Stage 3 Modeling, Fate of Particle Mass Percentages, Run 16 – No Action Scenario



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Legend:

- Silt Lenses
- Basal Silt Layer
- Extraction Well Screened Interval

Revised FS-1 Model Cross Section
Run 17 - K-1 and K-2 Bog Remediation Active

Massachusetts Military Reservation

Drawing Version No.: Rev 0.	Drawn by: JKD		Figure No.
Date: 2/4/99	Checked by: PMC		42

Figure 42. Revised FS-1 Model Cross Section, Run 17 – K-1 and K-2 Bog Remediation Active

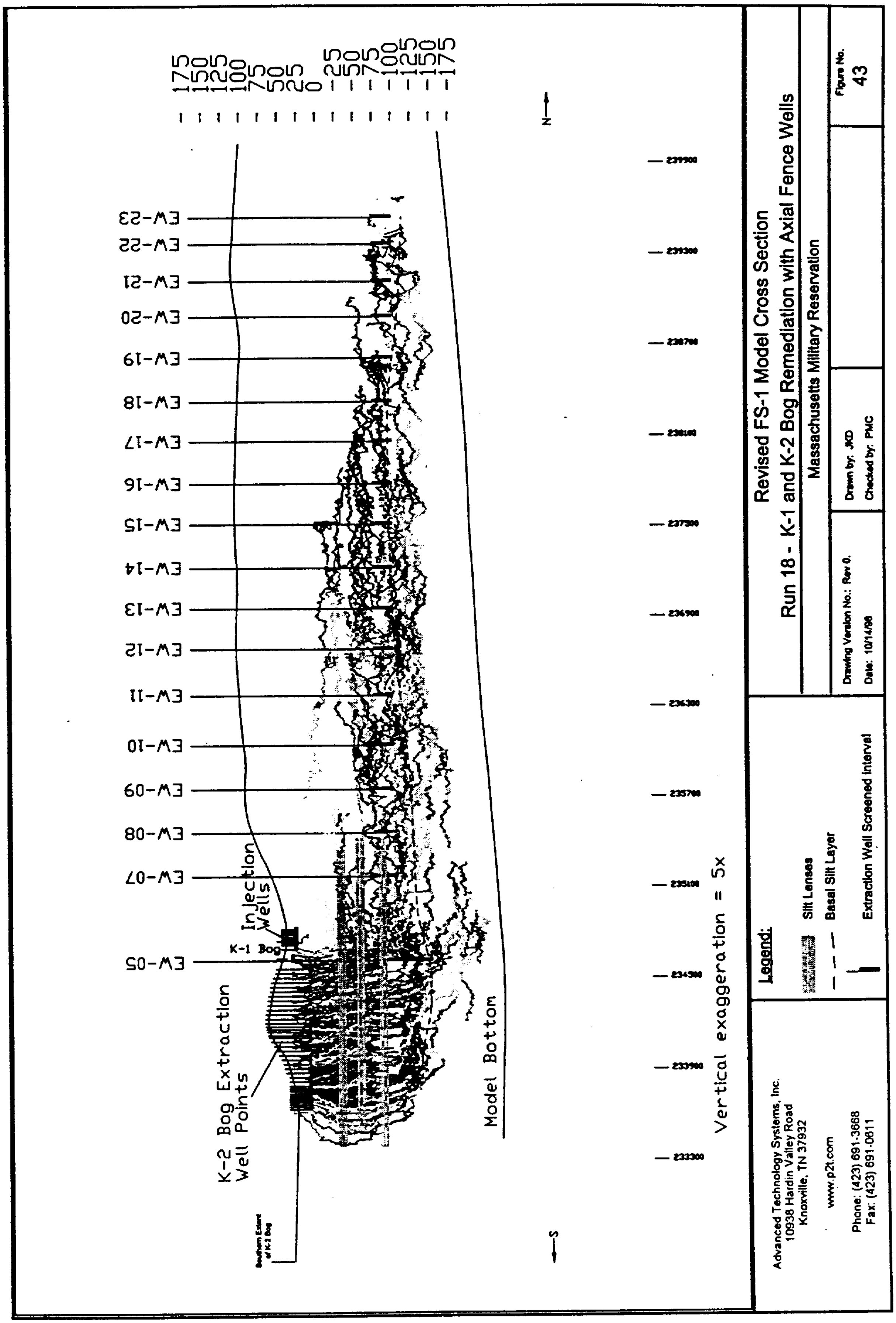
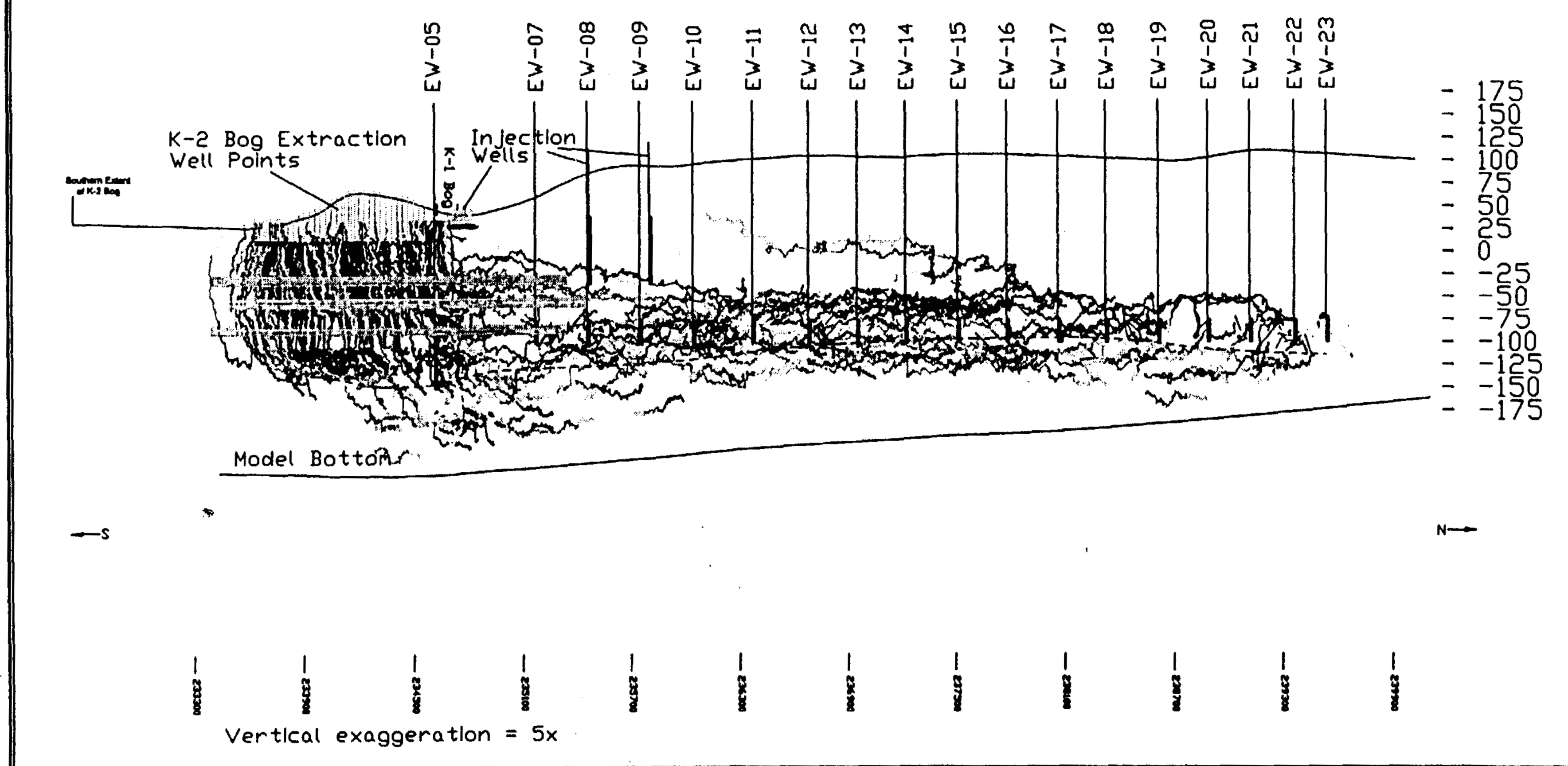


Figure 43. Revised FS-1 Model Cross Section, Run 18 – K-1 and K-2 Bog Remediation with Axial Fence Wells

Figure 44. Revised FS-1 Model Cross Section, Run 19 – K-1 and K-2 Bog Remediation with Axial Wells and Reinjection (400 gpm)



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: Silt Lenses Basal Silt Layer Extraction Well Screened Interval	Revised FS-1 Model Cross Section Run 19 - K-1 and K-2 Bog Remediation with Axial Wells and Reinjection (400 gpm) Massachusetts Military Reservation

Drawing Version No.: Rev 0. Date: 2/4/99	Drawn by: JKD Checked by: PMC		Figure No. 44

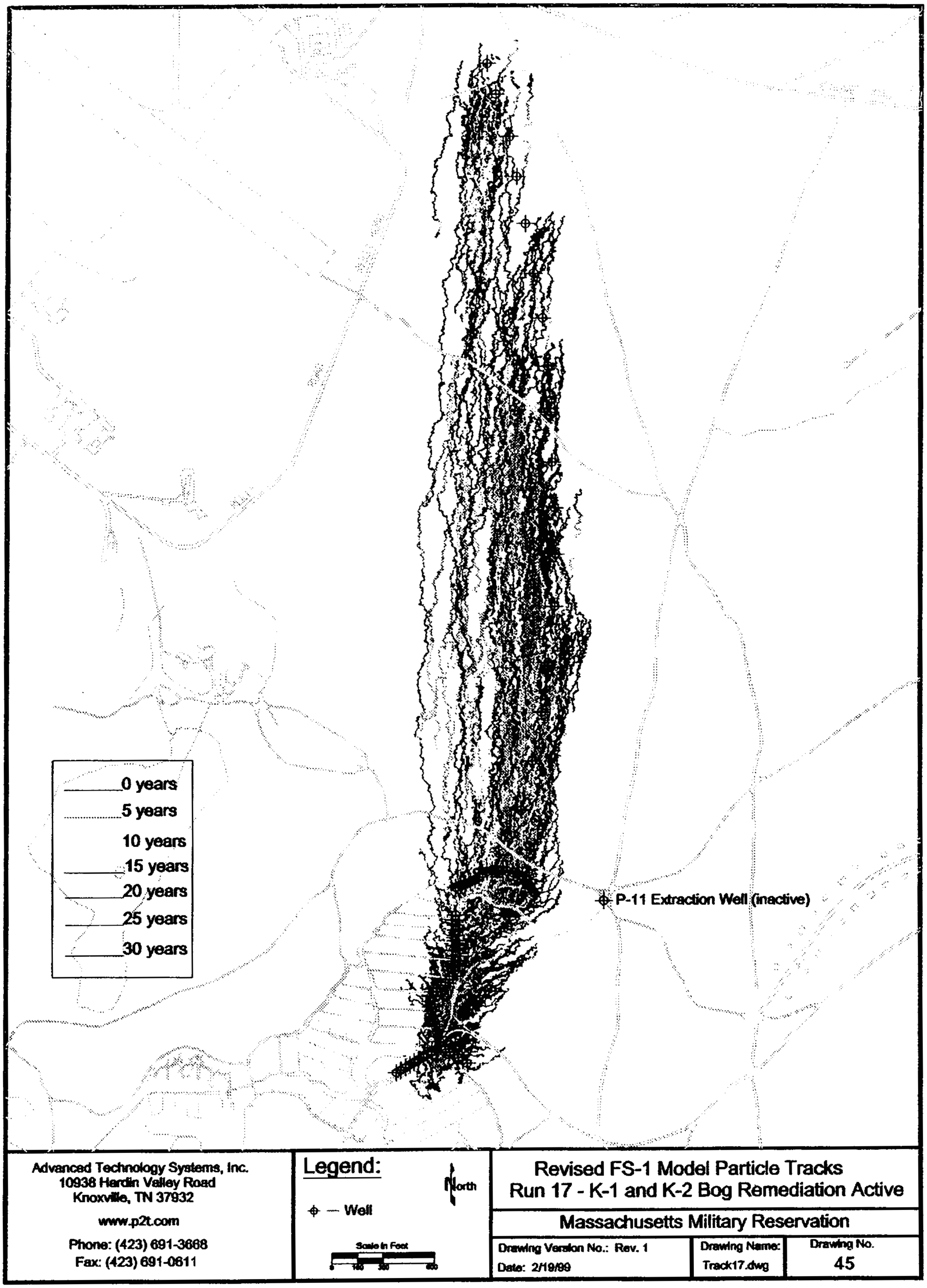
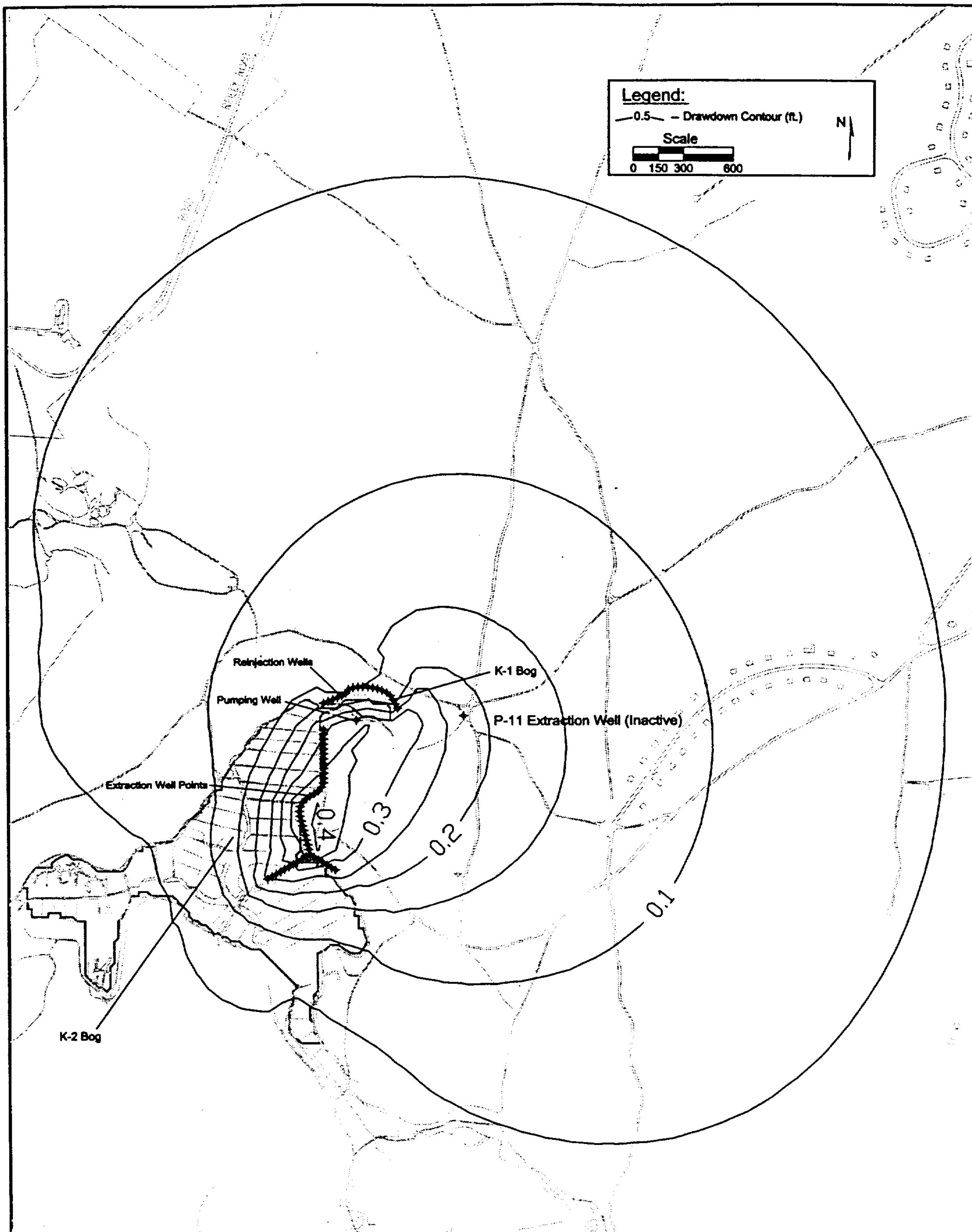


Figure 45. Revised FS-1 Model Particle Tracks, Run 17 – K-1 and K-2 Bog Remediation Active



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Run 17 - Revised FS-1 Model Drawdown Massachusetts Military Reservation			
	Drawing Version No.: Rev. 0 Date: 2/19/99	Drawn by: JKD Checked by: KCB	Project I.D. JEG-98.06	Figure No. 46

Figure 46. Run 17 – Revised FS-1 Model Drawdown

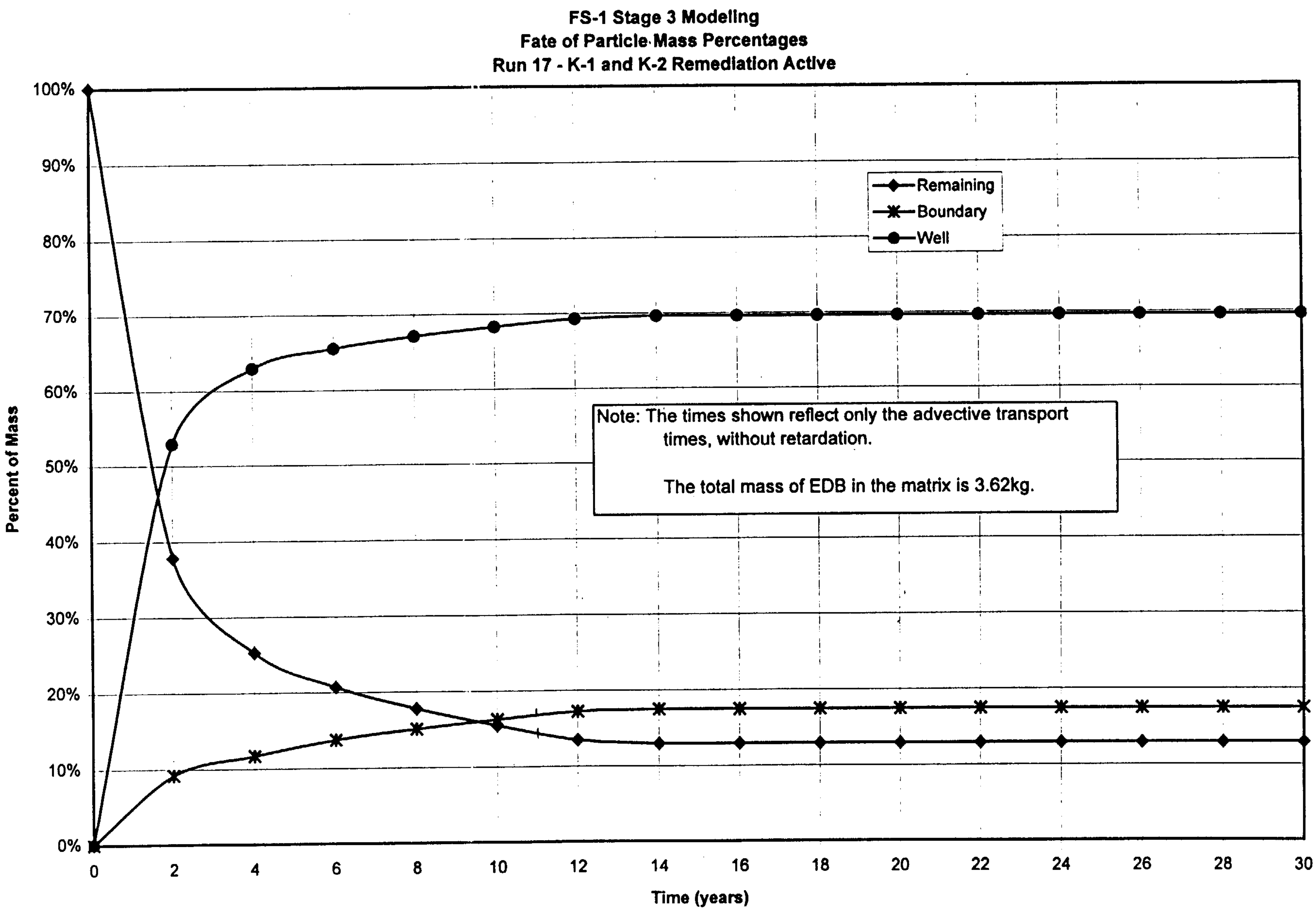


Figure 47. FS-1 Stage 3 Modeling, Fate of Particle Mass Percentages, Run 17 – K-1 and K-2 Remediation Active

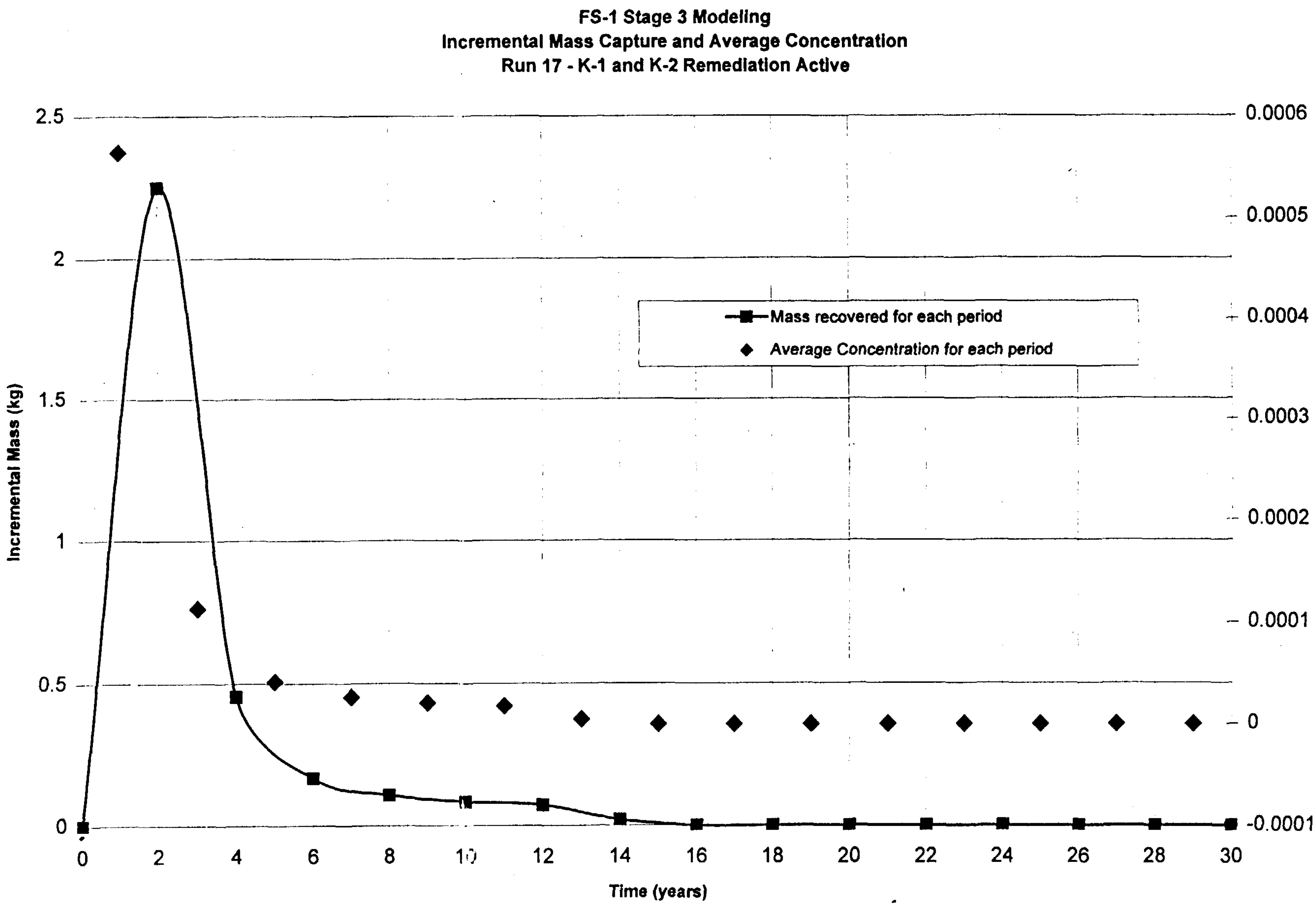
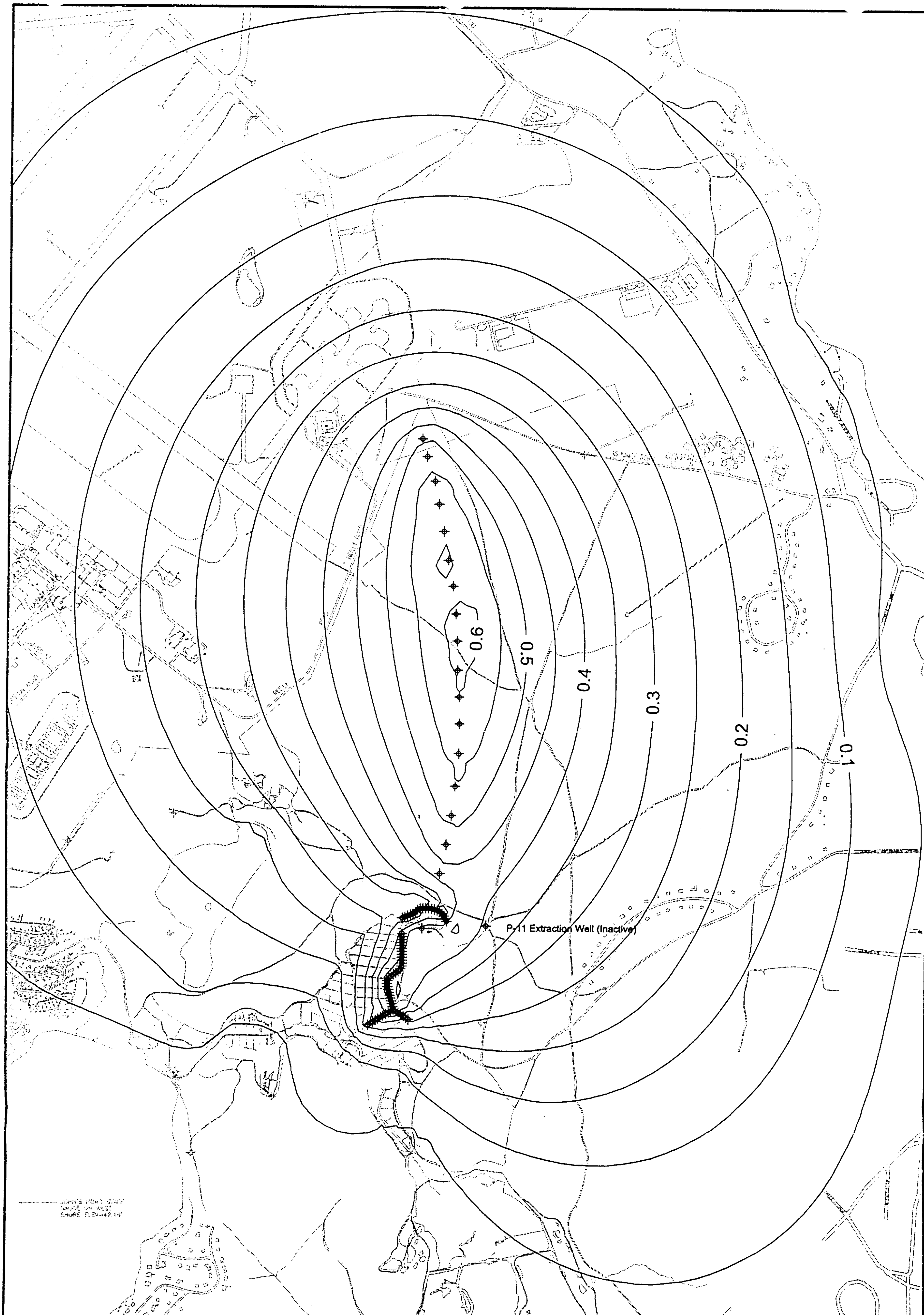


Figure 47a. FS-1 Stage 3 Modeling, Incremental Mass Capture and Average Concentration, Run 17 – K-1 and K-2 Remediation Active

Figure 48. Run 18 – Revised FS-1 Model Drawdown, K-1 and K-2 Remediation Active with Axial Wells



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	**Legend:** —0.05— - Drawdown (ft) ⌖ — Monitoring Well North Scale in Feet: 0 250 500 1000	Run 18 - Revised FS-1 Model Drawdown K-1 and K-2 Remediation Active with Axial Wells Massachusetts Military Reservation Drawing Version No.: Rev. 1 — Date: 2/19/99 Drawing Name: Drawdown.dwg Figure No. 48

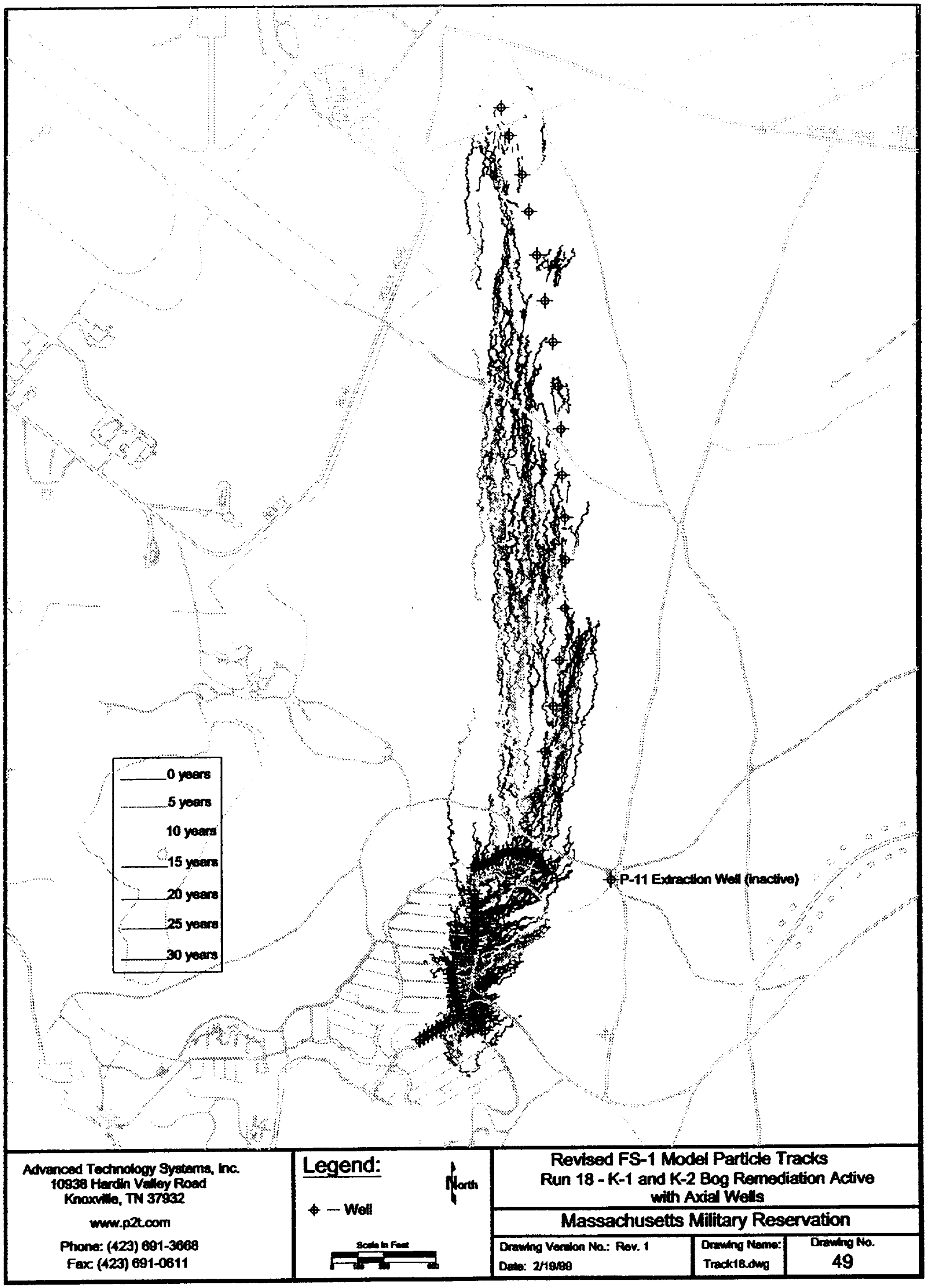


Figure 49. Revised FS-1 Model Particle Tracks,
Run 18 – K-1 and K-2 Bog Remediation Active with Axial Wells

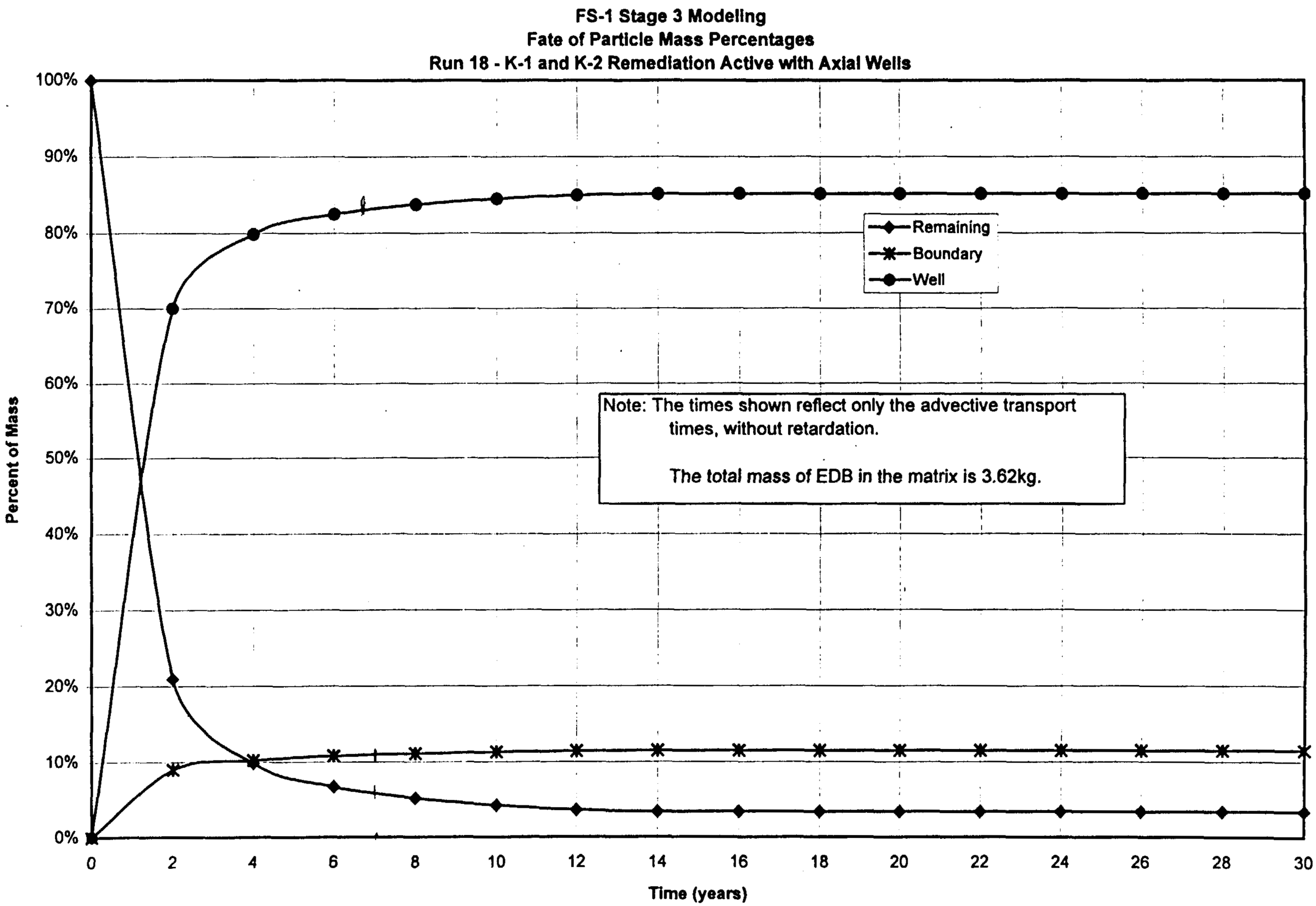


Figure 50. FS-1 Stage 3 Modeling, Fate of Particle Mass Percentages, Run 18 – K-1 and K-2 Remediation Active with Axial Wells

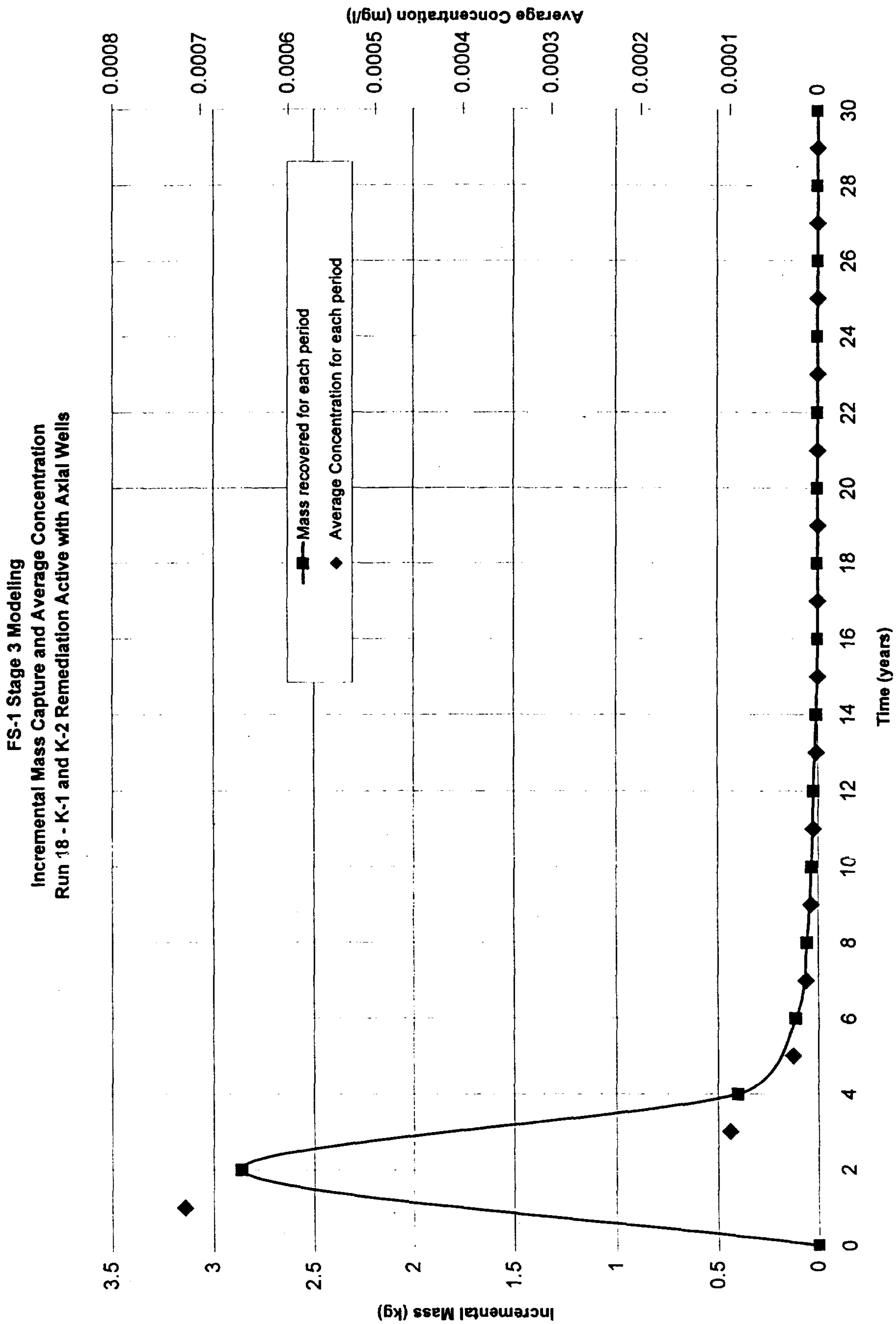


Figure 50a. FS-1 Stage 3 Modeling, Incremental Mass Capture and Average Concentration, Run 18 – K-1 and K-2 Remediation Active with Axial Wells

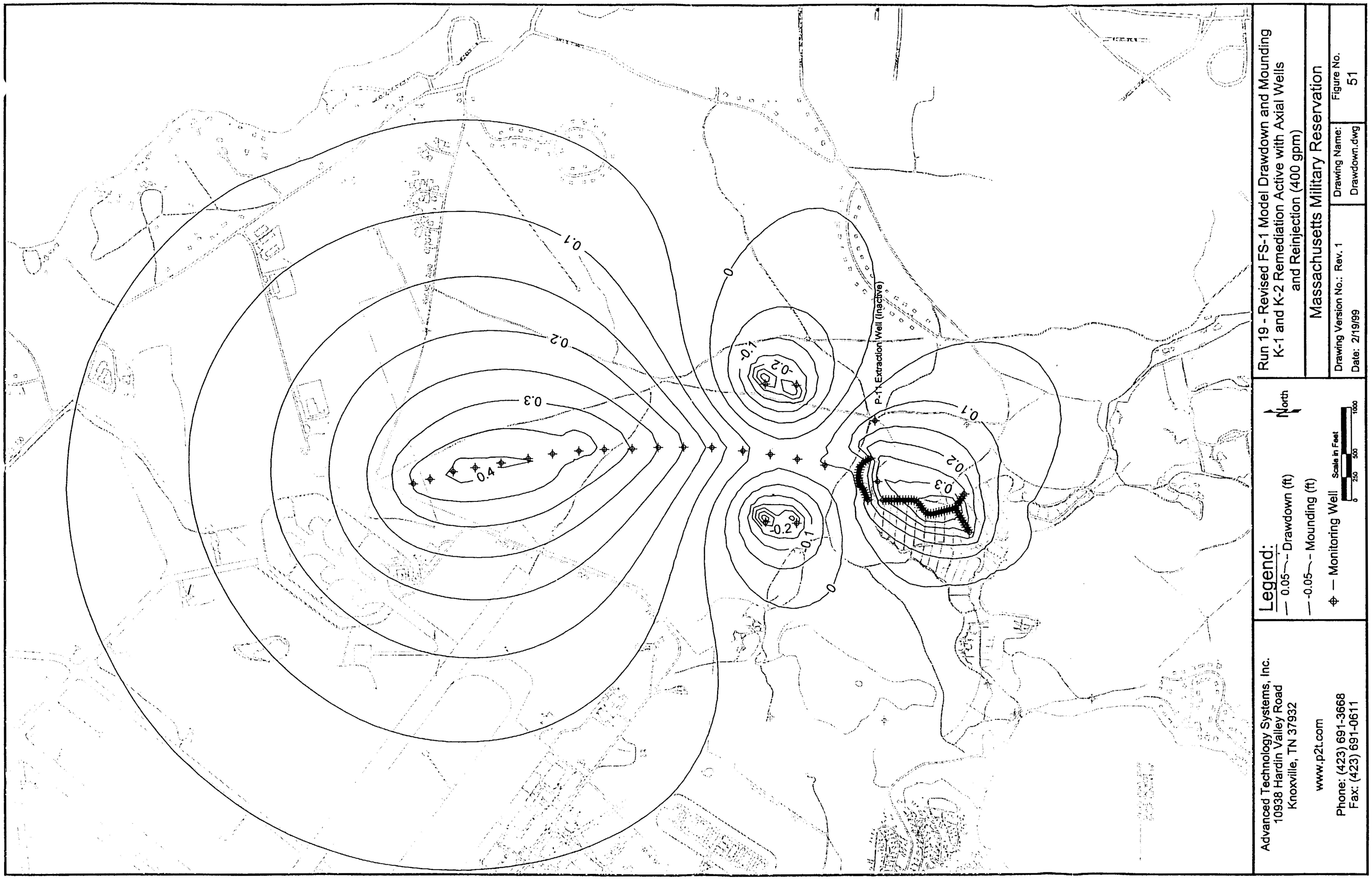


Figure 51. Run 19 – Revised FS-1 Model Drawdown and Mounding, K-1 and K-2 Remediation Active with Axial Wells and Reinjection (400 gpm)

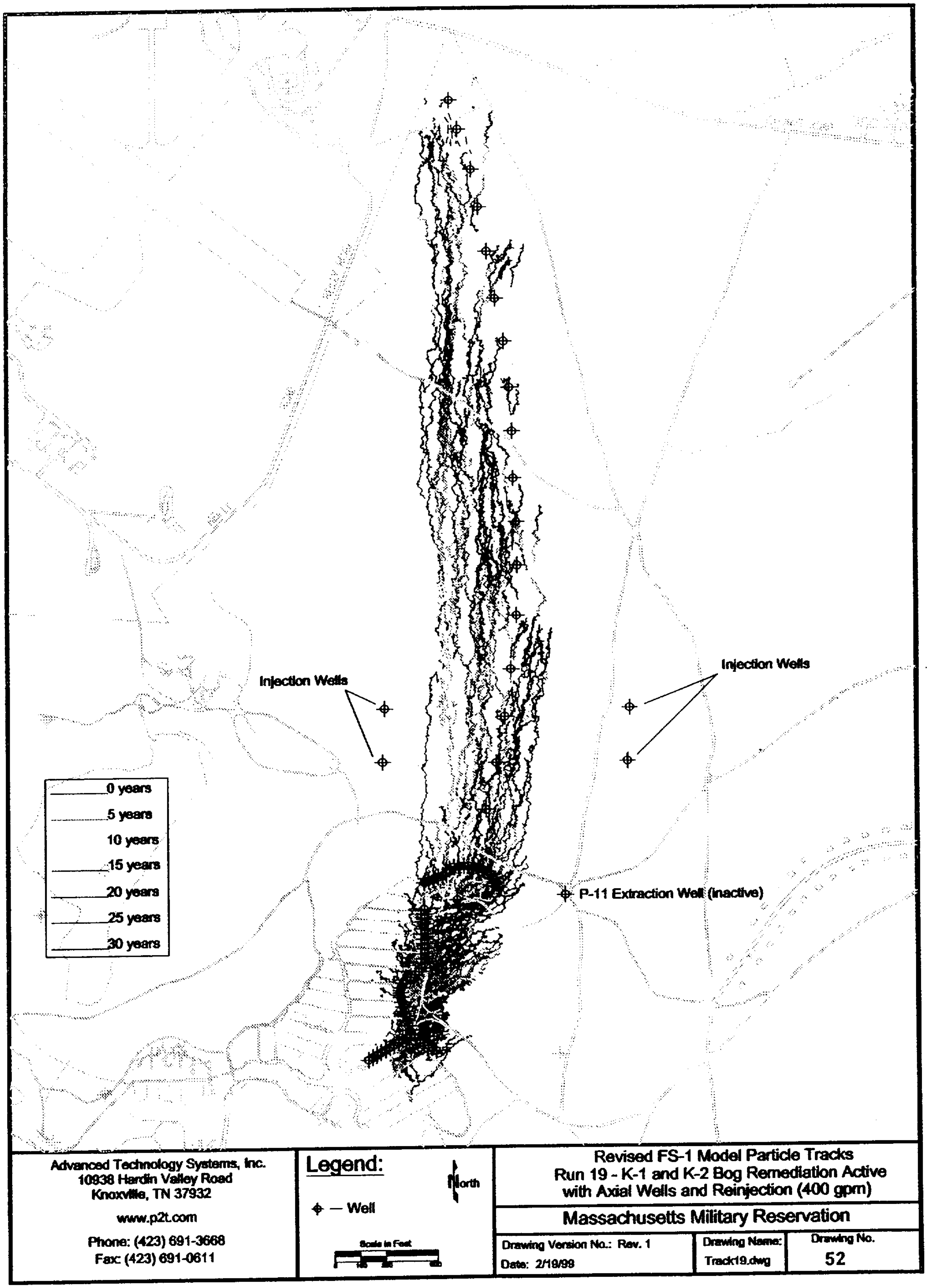


Figure 52. Revised FS-1 Model Particle Tracks,
Run 19 – K-1 and K-2 Bog Remediation Active with Axial Wells and Reinjection (400 gpm)

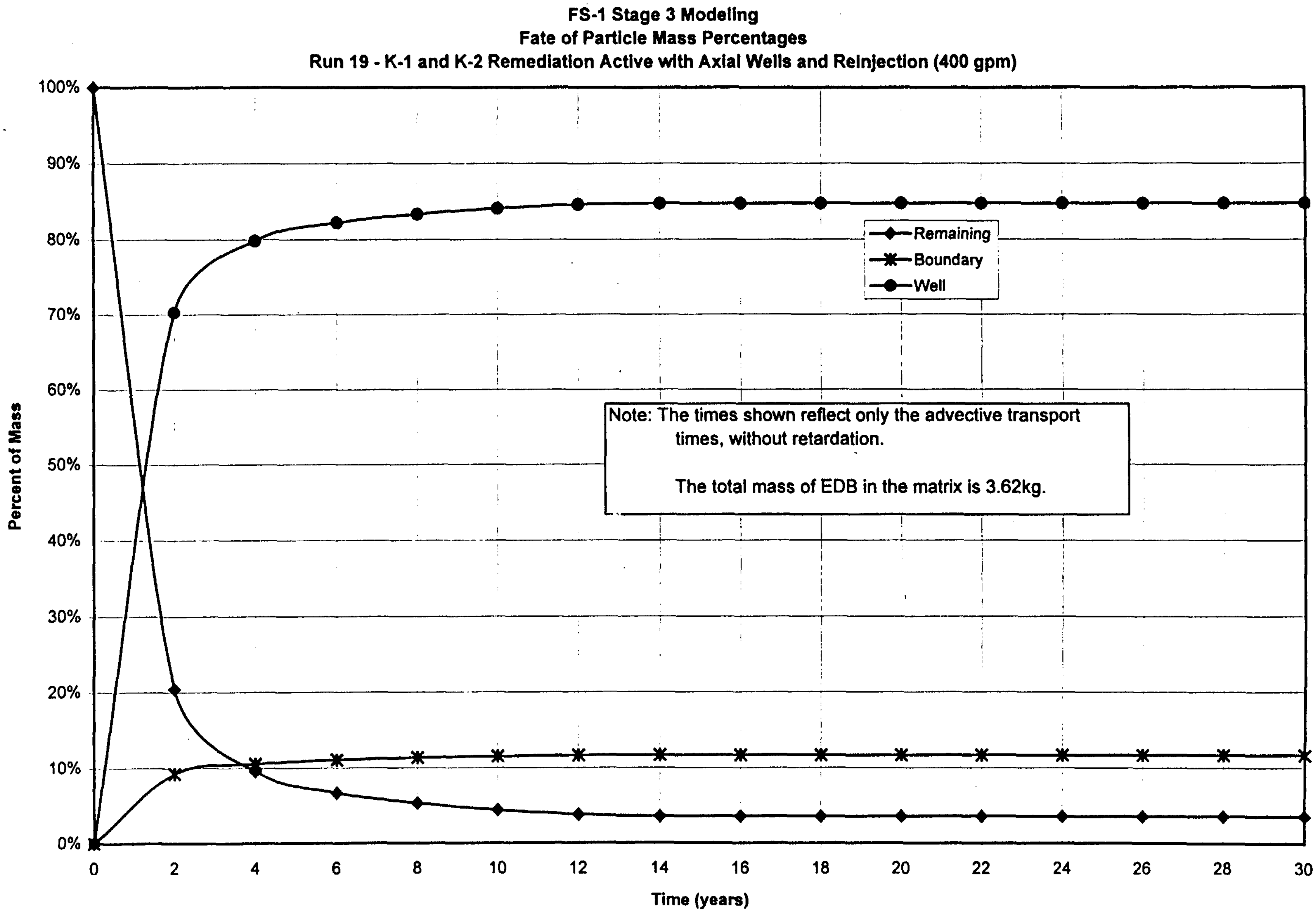


Figure 53. FS-1 Stage 3 Modeling, Fate of Particle Mass Percentages,
Run 19 – K-1 and K-2 Remediation Active with Axial Wells and Reinjection (400 gpm)

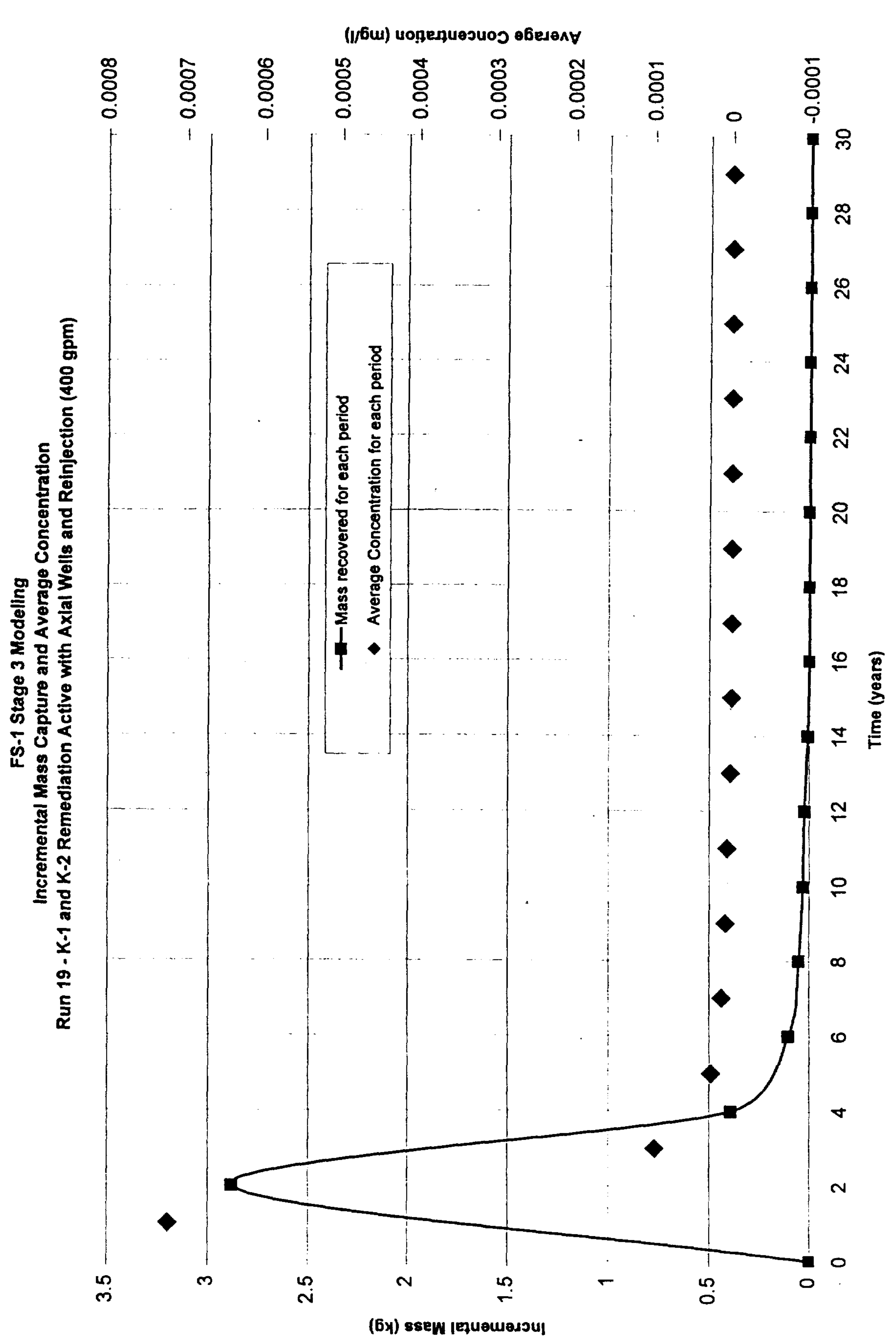
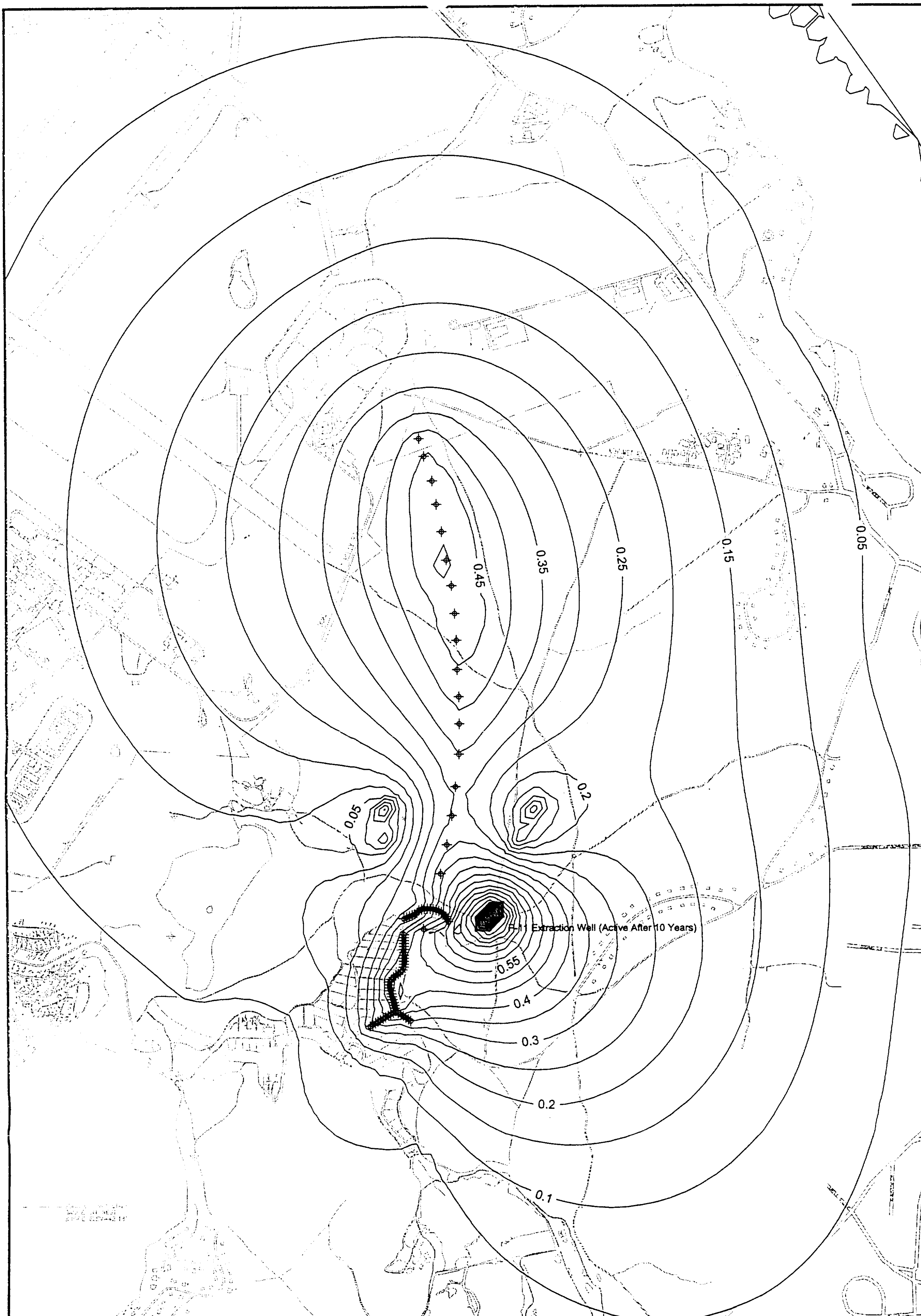


Figure 53a. FS-1 Stage 3 Modeling, Incremental Mass Capture and Average Concentration, Run 19 – K-1 and K-2 Remediation Active with Axial Wells and Reinjection (400 gpm)



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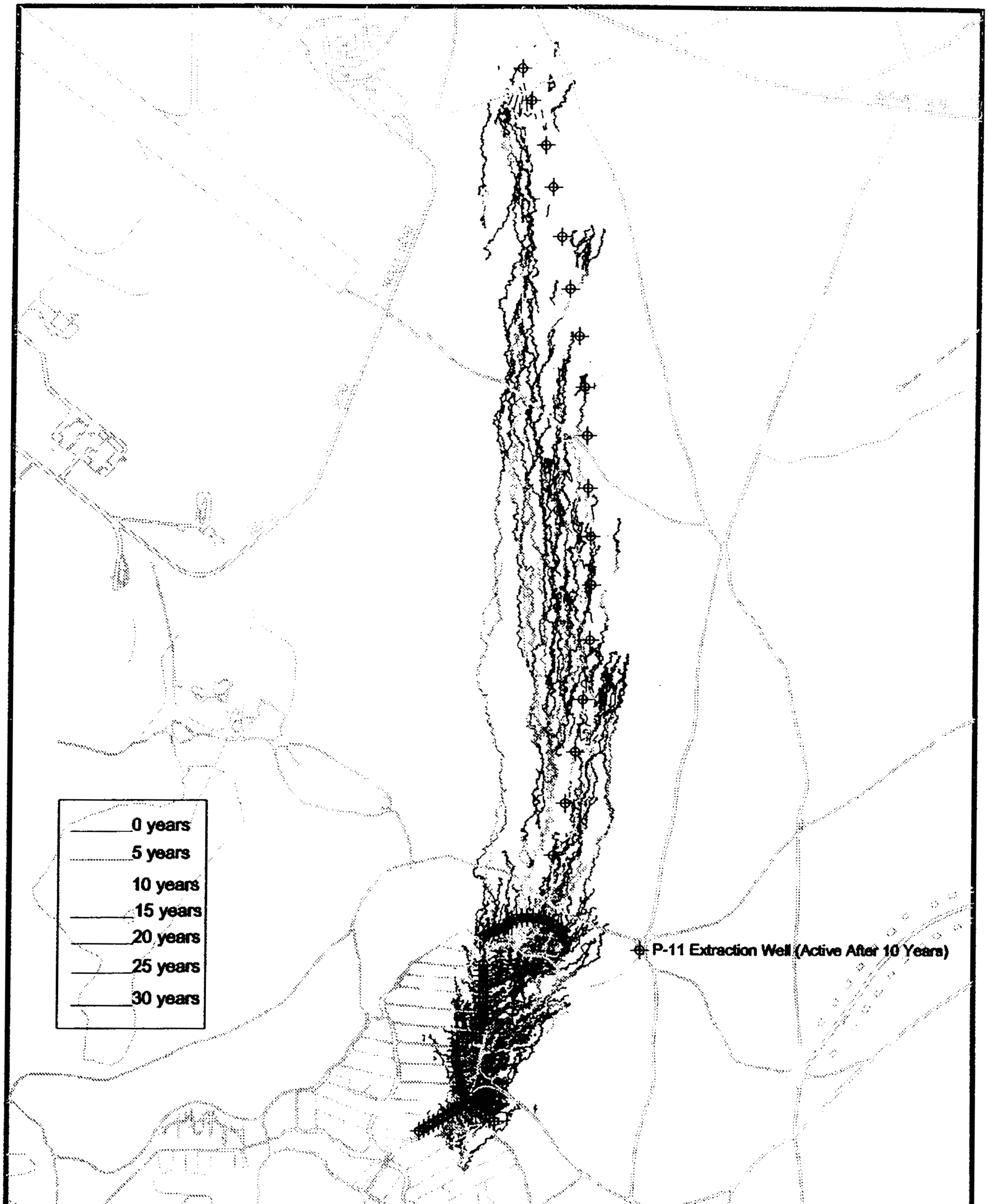
Legend:
— 0.05 — Drawdown (ft)
⌖ — Monitoring Well
North
Scale in Feet 0 250 500 1000

Run 20 - Revised FS-1 Model Drawdown
K-1 and K-2 Remediation Active with Axial Wells
P-11 Well Active After 10 Years

Massachusetts Military Reservation

Drawing Version No.: Rev. 0	Drawing Name:	Figure No.
Date: 2/18/99	Run20_drd.dwg	54

Figure 54. Run 20 – Revised FS-1 Model Drawdown, K-1 and K-2 Remediation Active with Axial Wells and Reinjection (400 gpm), P-11 Well Active After 10 Years



Advanced Technology Systems, Inc. 10936 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: North ⌖ — Well Scale in Feet	Revised FS-1 Model Particle Tracks Run 20 - K-1 and K-2 Bog Remediation Active P-11 Well Active After 10 Years Massachusetts Military Reservation		
		Drawing Version No.: Rev. 0 Date: 2/18/99	Drawing Name: Track20.dwg	Drawing No. 55

Figure 55. Revised FS-1 Model Particle Tracks, Run 20 – K-1 and K-2 Bog Remediation Active with Axial Wells and Reinjection (400 gpm), P-11 Well Active After 10 Years

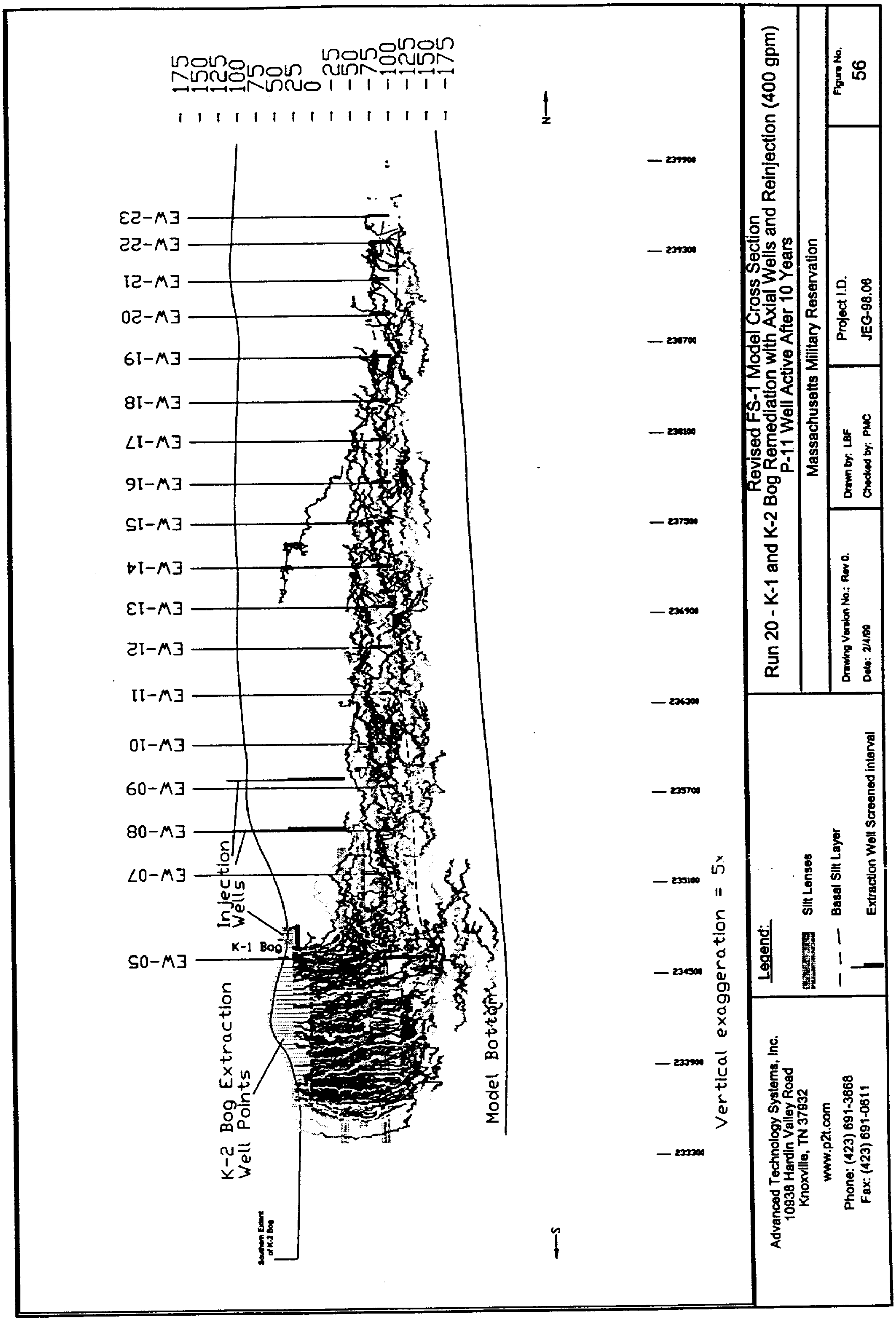


Figure 56. Revised FS-1 Model Cross Section, Run 20 – K-1 and K-2 Bog Remediation with Axial Wells and Reinjection (400 gpm), P-11 Well Active After 10 Years

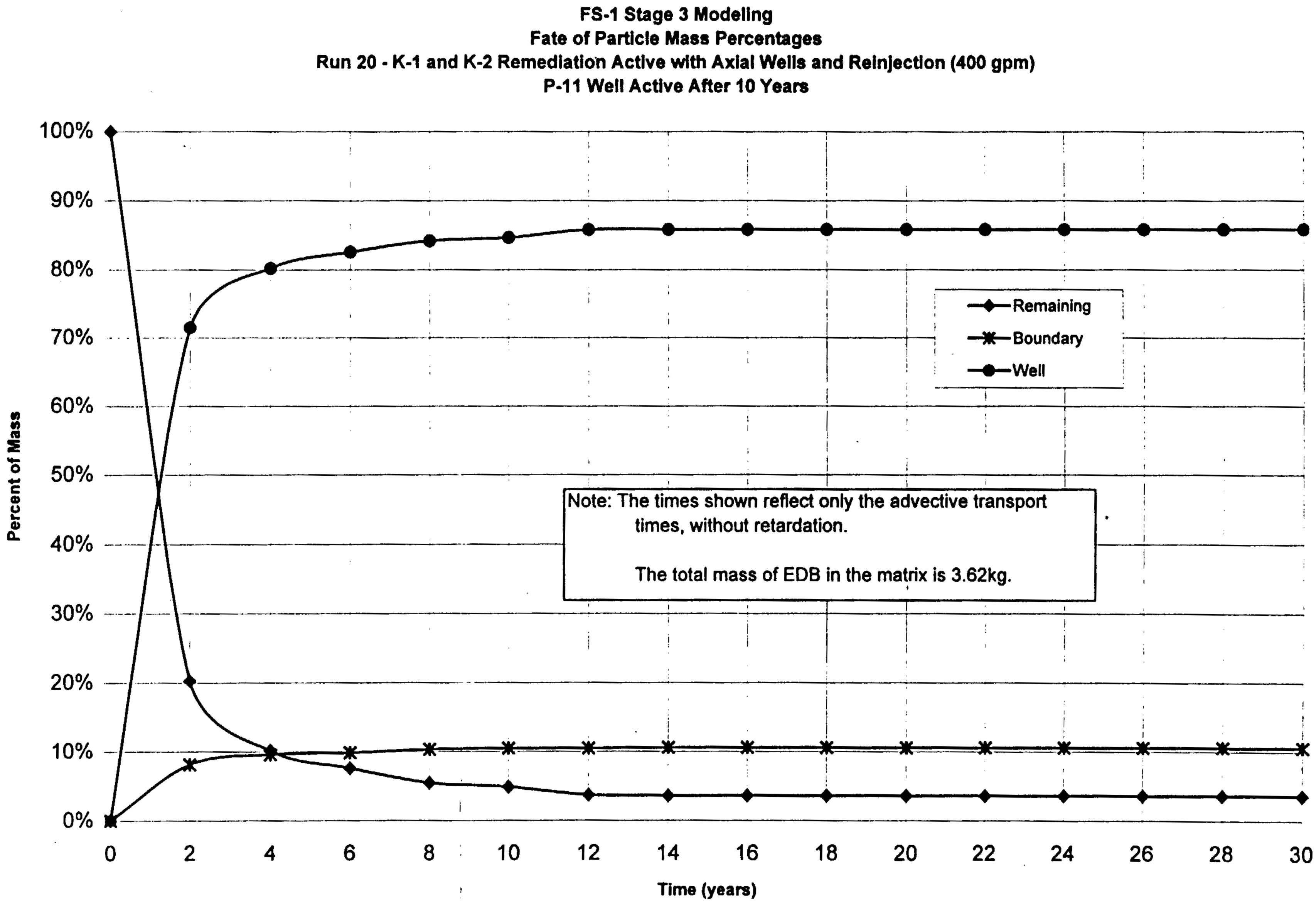


Figure 57. FS-1 Stage 3 Modeling, Fate of Particle Mass Percentages, Run 20 – K-1 and K-2 Remediation Active with Axial Wells and Reinjection (400 gpm), P-11 Well Active After 10 Years

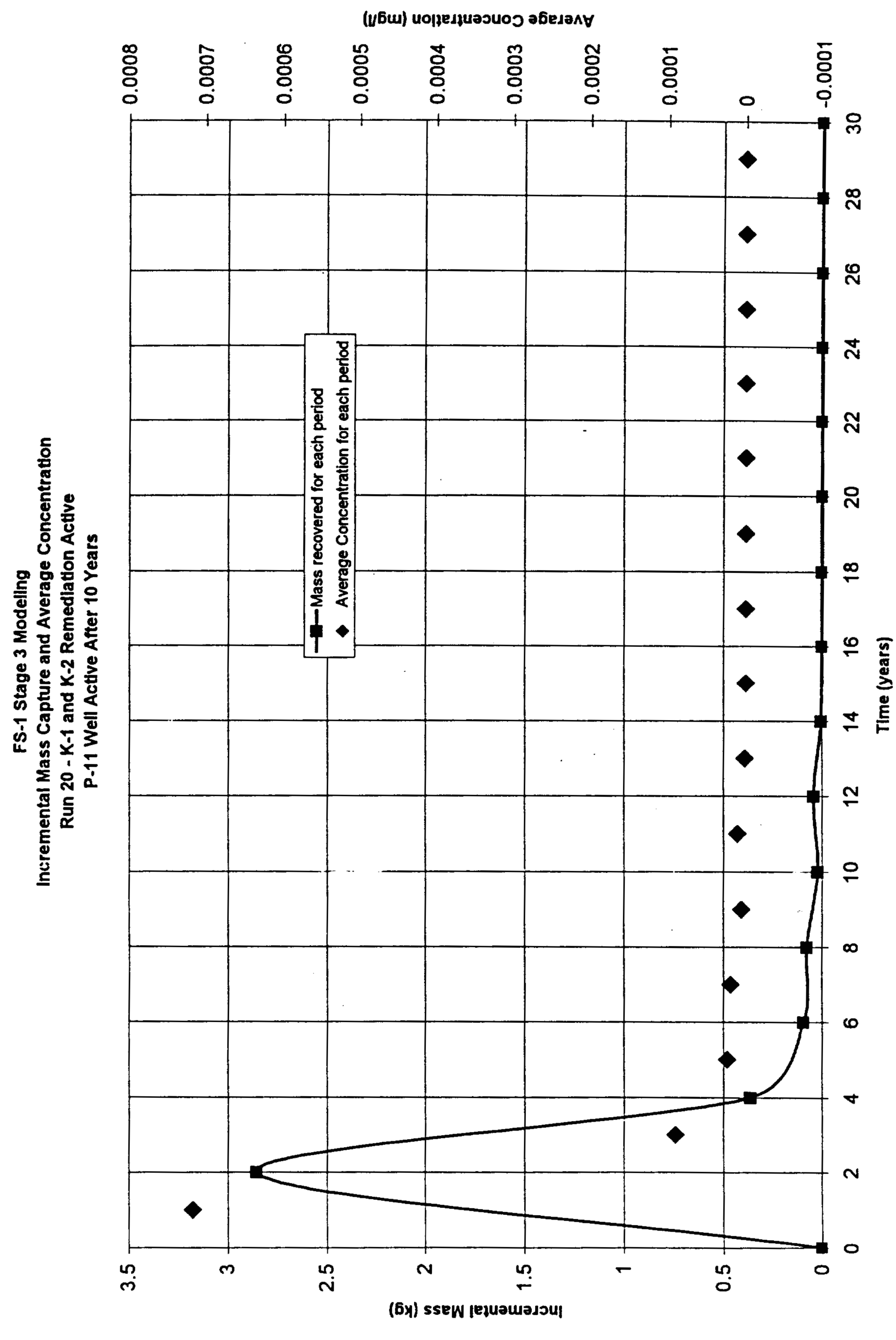


Figure 57a. FS-1 Stage 3 Modeling, Incremental Mass Capture and Average Concentration, Run 20 – K-1 and K-2 Remediation Active with Axial Wells and Reinjection (400 gpm), P-11 Well Active After 10 Years

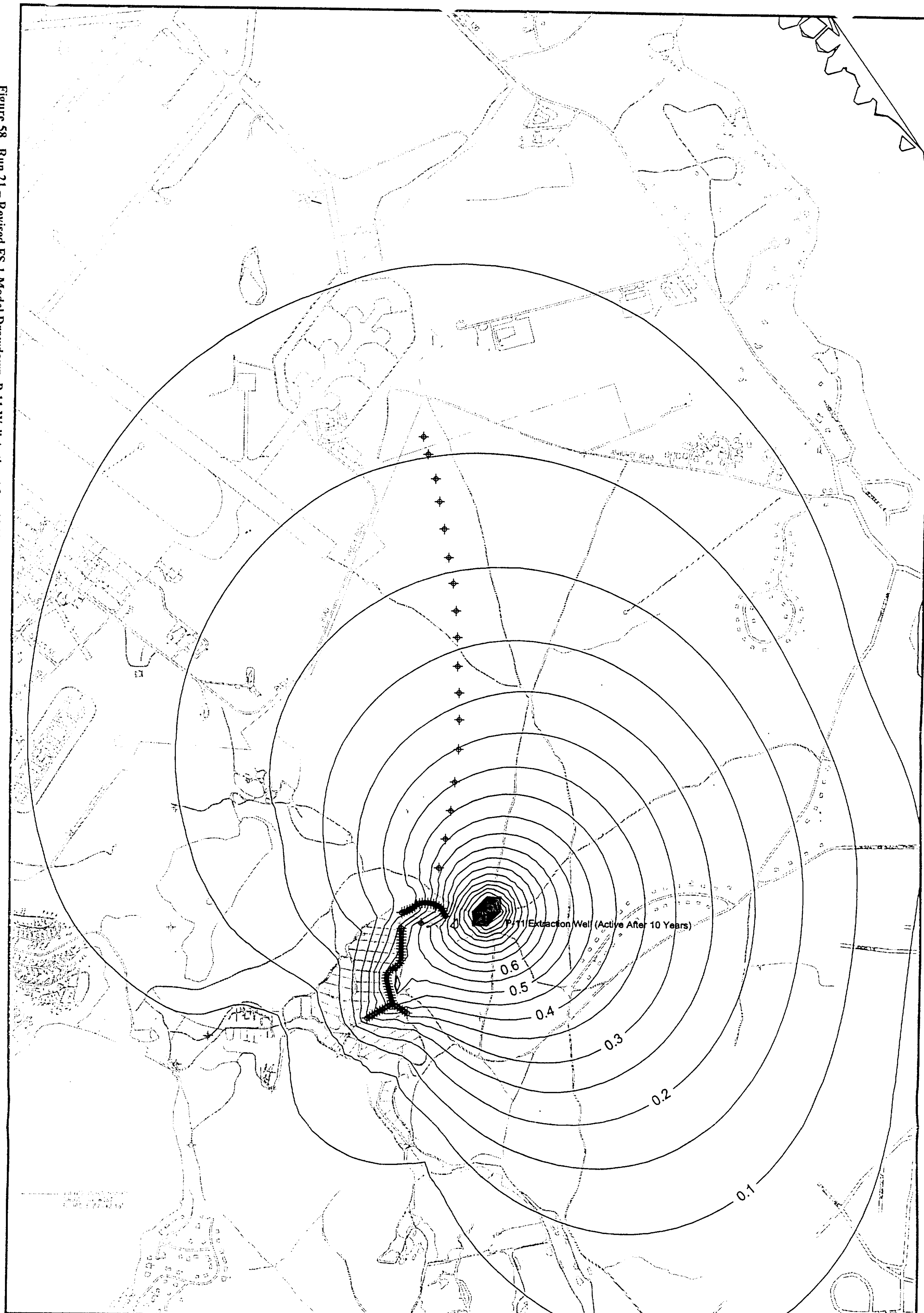


Figure 58. Run 21 – Revised FS-1 Model Drawdown, P-11 Well Active After 10 Years

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Phone: (423) 691-3668
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Legend:

— 0.05 – Drawdown (ft)

⌖ — Monitoring Well

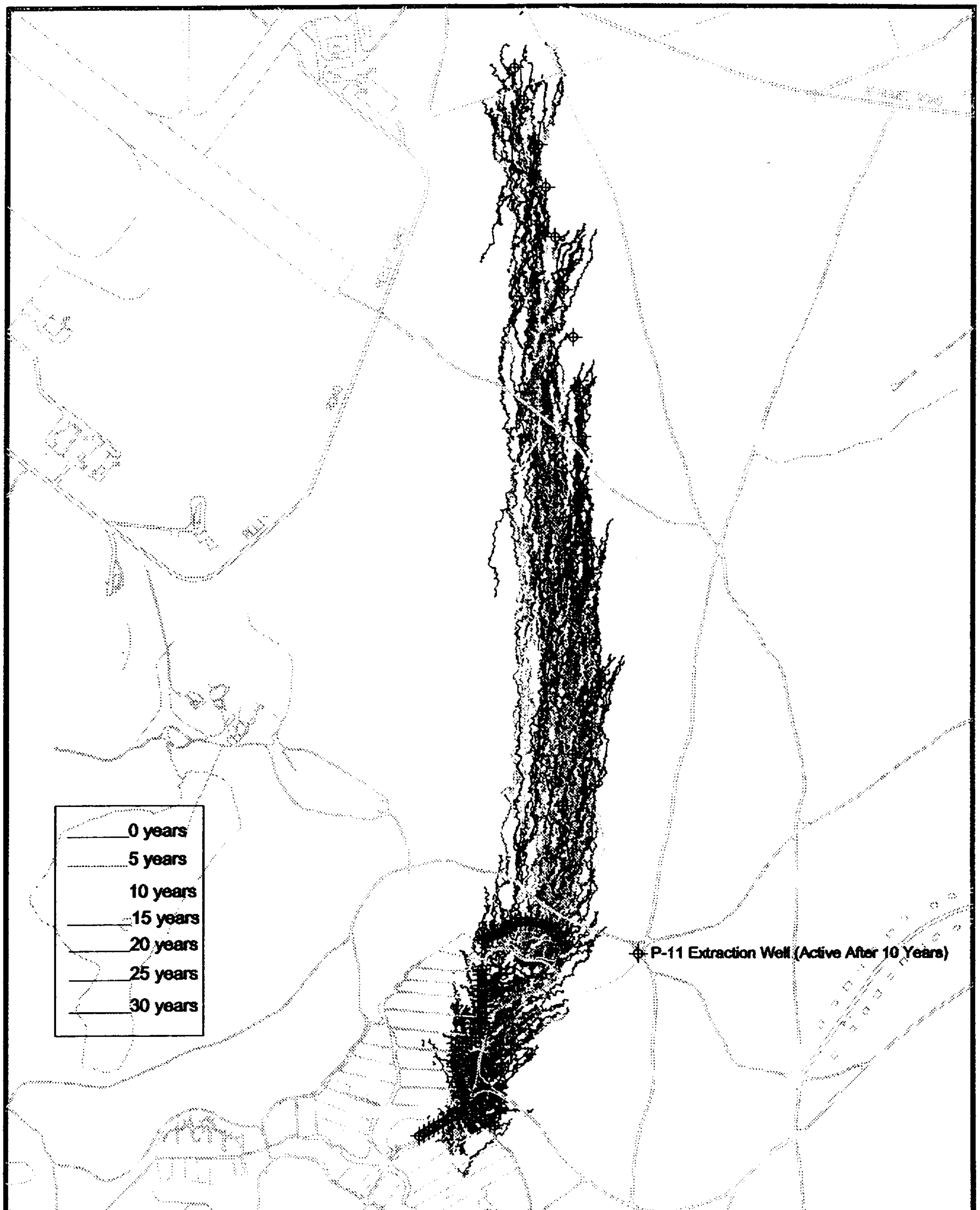
North

Scale in Feet: 0 250 500 1000

Revised FS-1 Model Drawdown
Run 21 - K-1 and K-2 Remediation Active
P-11 Well Active After 10 Years

Massachusetts Military Reservation

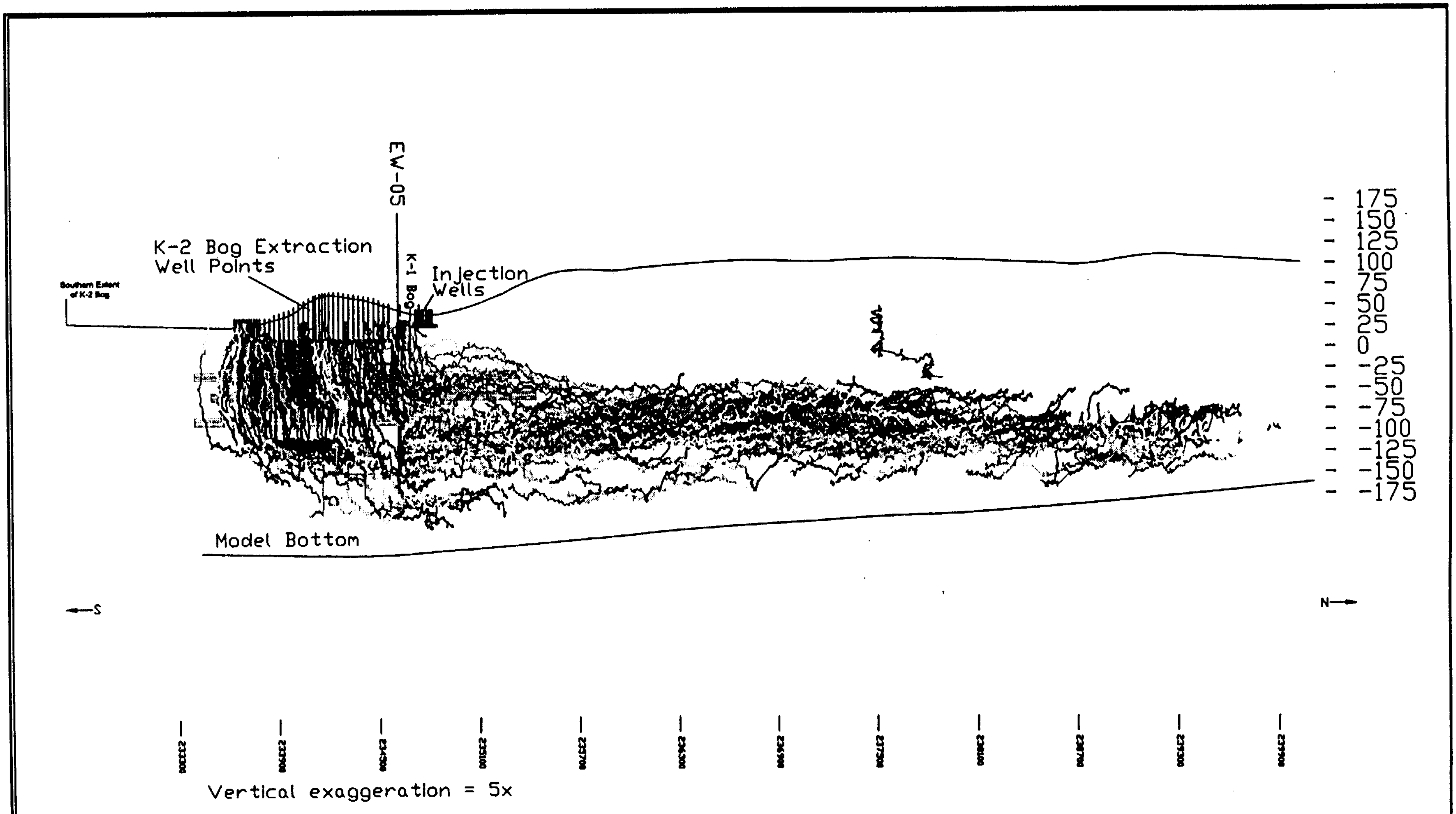
Drawing Version No.: Rev. 0	Drawing Name:	Figure No.
Date: 2/18/99	Run20_drd.dwg	58



Advanced Technology Systems, Inc. 10938 Hardin Valley Road Knoxville, TN 37932 www.p2t.com Phone: (423) 691-3668 Fax: (423) 691-0611	Legend: North ⌖ — Well Scale in Feet	Revised FS-1 Model Particle Tracks Run 21- K-1 and K-2 Bog Remediation Active P-11 Well Active After 10 Years Massachusetts Military Reservation Drawing Version No.: Rev. 0 — Date: 2/18/99 — Drawing Name: Track21.dwg — Drawing No. 59

Figure 59. Revised FS-1 Model Particle Tracks,
Run 21 – K-1 and K-2 Bog Remediation Active, P-11 Well Active After 10 Years

Figure 60. Revised FS-1 Model Cross Section,
Run 21 – K-1 and K-2 Bog Remediation Active, P-11 Well Active After 10 Years



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Fax: (423) 691-0611

Legend:

- Silt Lenses
- Basal Silt Layer
- Extraction Well Screened Interval

Revised FS-1 Model Cross Section
Run 21 - K-1 and K-2 Bog Remediation Active

Massachusetts Military Reservation

Drawing Version No.: Rev 0. Date: 2/19/99	Drawn by: JKD Checked by: PMC	Project I.D. JEG-98.06	Figure No. 60

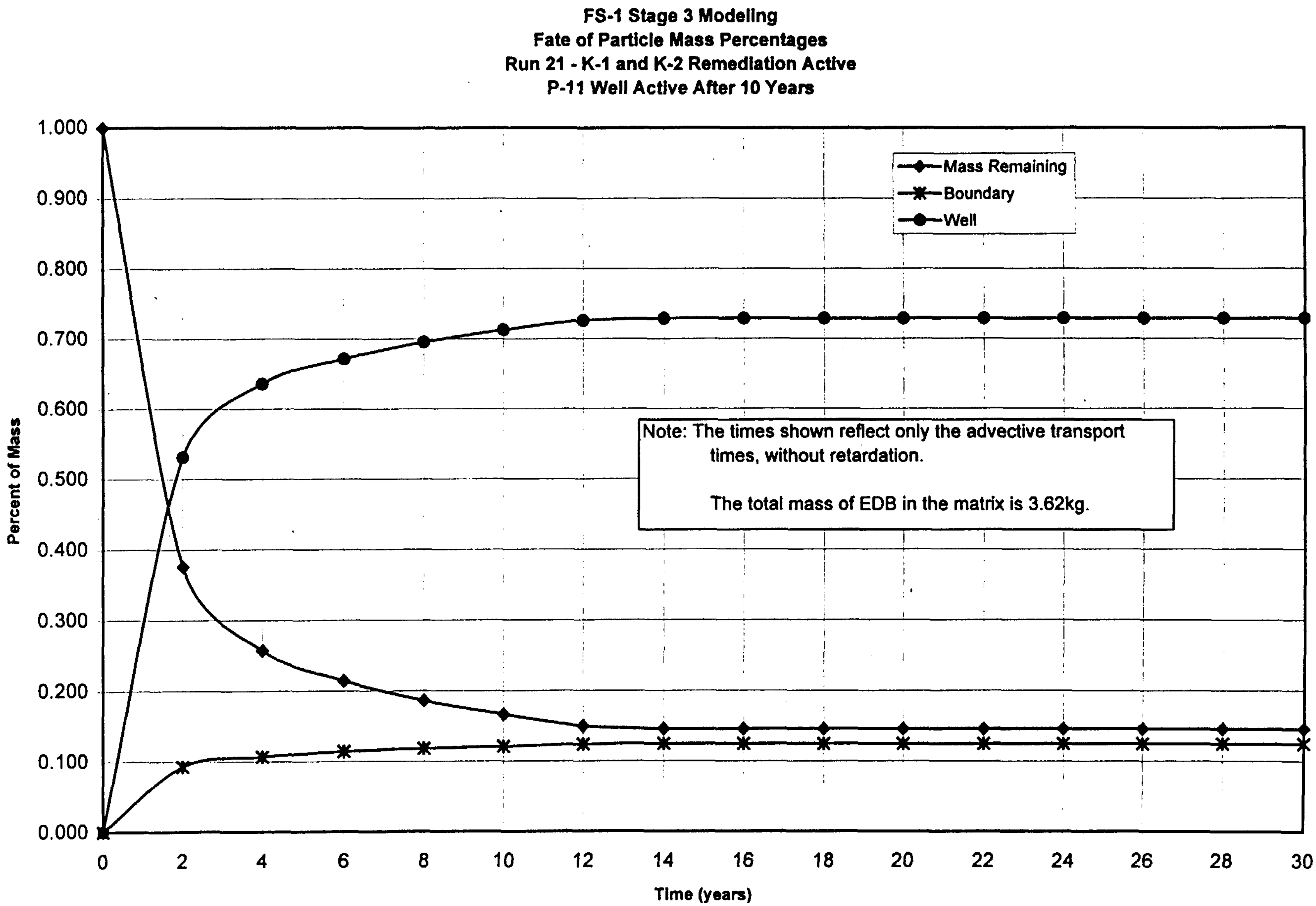

Figure 61. FS-1 Stage 3 Modeling, Fate of Particle Mass Percentages,
Run 21 – K-1 and K-Remediation Active, P-11 Well Active After 10 Years

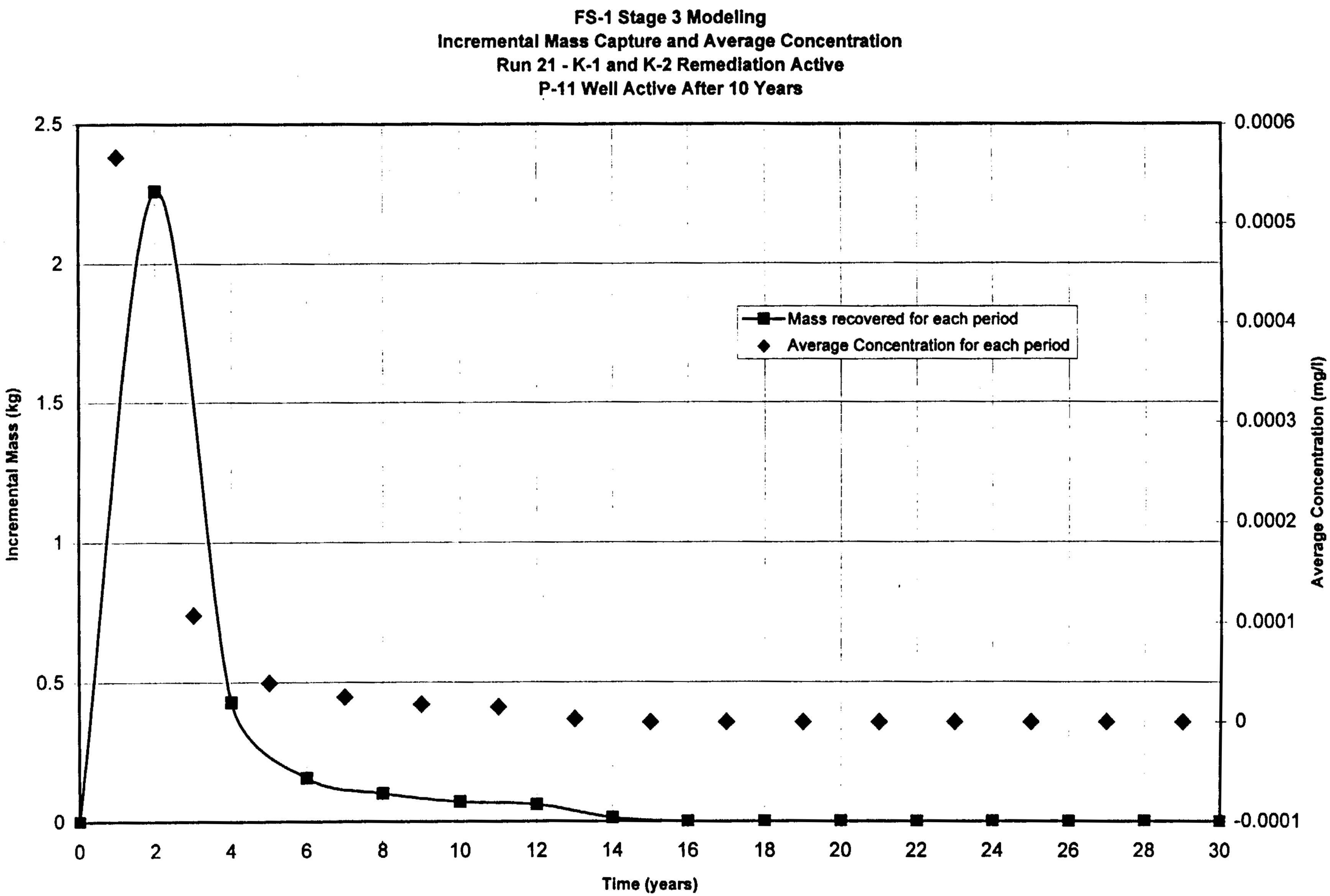

Figure 61a. FS-1 Stage 3 Modeling, Incremental Mass Capture and Average Concentration, Run 21 – K-1 and K-Remediation Active, P-11 Well Active After 10 Years

Table 1. Run Summary

Stage 1 FS-1 Modeling						Hydraulic Information				
Run Number	Date	Number of Extraction Wells	Number of Extraction Well Points representing an interceptor pipe	Number of Injection Wells	Number of Reinjection Well Points representing an reinjection pipe	Total Extraction Rate (gpd)	Total Reinjection Rate (gpd)	% of Total Mass Captured	Plume Seeds	Notes
1	10/1/98	0	0	0	0	0	0	0	4,673	No Action Scenario. Uniform discretization in X and Y directions (75 ft spacing).
2	10/7/98	40	0	0	0	439.0	0	50	4,673	Axial well fence along center of plume. Maximum drawdown = 0.7 ft.
3	10/8/98	26	0	0	0	298.5	0	30	4,673	3 well fences perpendicular to direction of plume with 5 additional wells in the K-1 and K-2 Bog areas.
4	10/8/98	21	0	0	0	280.0	0	17	4,673	2 small well fences and another larger well fence perpendicular to direction of plume with an axial fence in the K-1 and K-2 Bog areas.
5	10/9/98	40	0	0	0	622.5	0	70	4,673	Same configuration as Run 2 with a higher total pumping rate. Maximum drawdown >0.8 ft.
6	10/9/98	27	0	0	0	565.0	0	56	4,673	Same configuration as Run 3 with a higher total pumping rate.
7	10/9/98	23	0	0	0	997.5	0	77	4,673	A variation on Run 5 with fewer wells and a higher total pumping rate. Maximum drawdown >1.25 ft.

Stage 2 FS-1 Modeling						Hydraulic Information				
Run Number	Date	Number of Extraction Wells	Number of Extraction Well Points representing an interceptor pipe	Number of Injection Wells	Number of Reinjection Well Points representing an reinjection pipe	Total Extraction Rate (gpd)	Total Reinjection Rate (gpd)	% of Total Mass Captured	Plume Seeds	Notes
8	11/3/98	0	0	0	0	0	0	0	250	No Action Scenario. Rediscretized to focus on the K-1 and K-2 Bog areas. Smaller plume seeding limited to K-1 and K-2 areas.
9	11/4/98	1	0	0	11	200	100	30	250	Pumping EW-05 (screen -40 to -100) at 200 gpm with reinjection evenly spread among 11 well points representing the reinjection pipe north of the K-1 Bog
10	11/4/98	1	0	0	11	400	200	33	250	Pumping EW-05 at 400 gpm with same reinjection configuration but higher rate.
11	11/5/98	1	0	0	11	600	300	38	250	Pumping EW-05 at 600 gpm with same reinjection configuration but higher rate.
12	11/11/98	1	0	0	11	200	200	28	250	Same configuration as Run 9 with the EW-05 screened interval lowered to -90 to -150. Reinjection of all extracted water.
13	11/11/98	1	26	0	11	500	200	91	250	Same configuration as Run 12 with addition of an interceptor pipe 10' below water table pumped at 300 gpm and represented by well points.
14	11/12/98	1	26	0	11	500	200	88	250	Same configuration as above with interceptor pipe (well points) 30' below water table pumped at 300 gpm.
15	11/13/98	1	26	0	11	600	200	92	250	Same configuration as above with interceptor pipe (well points) 10' below water table pumped at 400 gpm.

Stage 3 FS-1 Modeling						Hydraulic Information				
Run Number	Date	Number of Extraction Wells	Number of Extraction Well Points representing an interceptor pipe	Number of Injection Wells	Number of Reinjection Well Points representing an reinjection pipe	Total Extraction Rate (gpd)	Total Reinjection Rate (gpd)	% of Total Mass Captured	Plume Seeds	Notes
16	1/29/99	0	0	0	0	0	0	0	44,824	No Action Scenario. Rediscretized to account for addition of axial well fence from Run 7. New plume seeds.
17	1/29/99	1	45	0	19	600	200	70	44,824	Refinement of Run 15 w/ new location of reinjection pipe north of the K-1 Bog and the interceptor pipe.
18	2/1/99	18	45	0	19	1,000	200	85	44,824	Same configuration as Run 17 with addition of the 17 northernmost axial wells from Run 7 pumped at 23.5 gpm instead of 37.5 gpm.
19	2/2/99	18	45	4	19	1,000	600	85	44,824	Same configuration as Run 18 with addition of 2 reinjection wells flanking each side of the plume above the K-1 Bog.
20	2/19/99	18	45	4	19	1,000	600	85	44,824	Same configuration as Run 19 with P-11 well activated at 350 gpm after 10 years.
21	2/19/99	1	45	0	19	600	200	73	44,824	Same configuration as Run 17 with P-11 well activated at 350 gpm after 10 years.

APPENDIX C

FS-1 FEASIBILITY STUDY COST ESTIMATES

ESTIMATED COST

FS-1 FEASIBILITY STUDY

ALTERNATIVE 2B

INSTITUTIONAL ACTION with BOG SEPERATION/PROTECTION

10 Year Estimate

Direct Cost of Limited Action with Bog Seperation Activities.			
A: Administrative Costs, Institutional Controls			**$250,000**
B: Capital Costs			
1. Treatment Facility Construction	**$2,355,000**		
2. Extraction/ Injection System	**$587,000**		
3. Berms	**$1,010,000**		
Total			**$3,952,000**
C: Well Sampling, Source Area			**$15,000**
Operating and Maintenance Costs 1- 11 (includes 5% annual inflation)			
A: Treatment Facility O&M: Years 1- 11	**$4,731,000**		
B: Longterm Groundwater Monitoring: Years 1 - 11	**$615,000**		
C: System Effectivenss Monitoring: Years 1 - 11	**$142,000**		
D: Five Year Reviews: 5, 10 years	**$55,000**		
Total O&M costs Years 1 - 11		**$5,543,000**	
Present Worth O&M @ 7%			**$5,206,000**
Alternative 2B: Present Value Cost			**$9,423,000**

Capital costs and treatment facility operation and maintenance extracted from estimate provided by Jacobs Engineering Group

ESTIMATED COST
FS-1 FEASIBILITY STUDY
ALTERNATIVE 3
AXIAL WELL EXTRACTION/TREATMENT/REINJECTION
10 year estimate

Direct Cost of Extraction/Treatment/Reinjection			
A: Administrative Costs, Institutional Controls			$250,000
B: Capital Costs			
1. Property Acquisition	$340,000.00		
1. Treatment Facility Construction	$2,355,000.00		
2. Extraction/ Injection System	$1,681,000.00		
Total			$4,626,000
C: Well Sampling, Source Area			$15,000
Operating and Maintenance Costs (includes 5% annual inflation)			
A: Treatment Facility O&M: Years 1-11	$3,420,000.00		
B: Longterm Groundwater Monitoring: Years 1 - 11	$353,000.00		
C: System Effectivenss Monitoring: Years 1 - 11	$81,000.00		
D: Five Year Reviews: 5, 10 years	$24,000.00		
Total O&M costs Years 1 - 11		$4,041,000	
Present Worth O&M @ 7%			3,808,000
Alternative 3: Present Value Cost			$8,699,000

Capital cost ad treatment facility operation and maintenance cost extracted from estimate provided by Jacobs Engineering Group

ESTIMATED COST
FS-1 FEASIBILITY STUDY
ALTERNATIVE 3B
AXIAL EXTRACTION/TREATMENT/REINJECTION with BOG SEPERATION/PROTECTION
10 Year Estimate

Direct Cost of Extraction/Treatment/Reinjection			
A: Administrative Costs, Institutional Controls			$250,000
B: Capital Costs			
1. Property Acquisition	$340,000		
2. Treatment Facility Construction	$3,260,000		
3. Extraction/ Injection System	$1,525,000		
4. Berms	$1,010,000		
Total			$6,385,000
C: Well Sampling, Source Area			$15,000
Operating and Maintenance Costs (includes 5% annual inflation)			
A: Treatment Facility O&M: Years 1- 7	$3,691,000		
B: Longterm Groundwater Monitoring: Years 1 - 7	$353,000		
C: System Effectivenss Monitoring: Years 1 - 7	$81,000		
D: Five Year Reviews: 5	$24,000		
Total O&M costs Years 1 - 7		$4,149,000	
Present Worth O&M @ 7%			$3,911,000
Alternative 3B: Present Value Cost			$10,561,000

Capital costs and treatment facility operation and maintenance cost extracted from estimate provided by Jacobs Engineering Group

APPENDIX D

FS-1 ANALYTICAL TABLES

Table 4.1
Analytical Results from Soil Collected at Fuel Spill Site 1
Pre-1997

Source		E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1991
Sample Location		36BS005048	36BS005054	36MS006015	36MS006048	36MS007030	36MS007048	36MS007065	36MS008047	36MS008047D	36MS008060
Sample Depth		48ft	54ft	15ft	48ft	30ft	48ft	65ft	47ft	47ft	60ft
Date Sampled		7/31/89	7/31/89	7/31/89	7/31/89	8/1/89	8/1/89	8/1/89	8/2/89	8/2/89	8/2/89
Chemical	CRQL/CRDL										
Volatiles (ug/Kg)											
Methylene Chloride	5	ND	ND	ND	ND	110000	ND	140000	ND	ND	70000
Acetone	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroethane	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Semivolatiles (ug/Kg)											
bis(2-Ethylhexyl)phthalate	330	ND	ND	ND	ND	ND	ND	ND	2300	ND	ND
Phenanthrene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Anthracene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fluoranthene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pyrene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)anthracene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chrysene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(b)fluoranthene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)pyrene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(g,h,i)perylene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acenaphthlene	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pesticides (ug/Kg)											
alpha-BHC	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlor epoxide	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan I	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDE	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endosulfan II	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDD	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDT	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methoxychlor	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Endrin ketone	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
alpha-Chlordane	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
gamma-Chlordane	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Metals(mg/Kg)											
Aluminum	200	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antimony	60	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barium	200	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chromium	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cobalt	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Iron	100	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	3	ND	2.1	1.3	1.7	1.1	4.8	ND	3	3	1.9
Magnesium	5000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Manganese	15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	40	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Potassium	5000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sodium	5000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Miscellaneous(mg/Kg)											
TOC	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
TPH	0.2	ND	ND	ND	ND	ND	95.8	ND	83.3	234	ND

Table 4.1
Analytical Results of Soil Collected at Fuel Spill Site 1
Pre-1997 (continued)

Source		E.C. Jordan 1991	E.C. Jordan 1991	E.C. Jordan 1989	E.C. Jordan 1989	E.C. Jordan 1990	HAZWRAP 1995	HAZWRAP 1995	HAZWRAP 1995	HAZWRAP 1995	HAZWRAP 1995	HAZWRAP 1995
Sample Location:		36BS411054	36MS413055	FS1-TB2	FS1-TB3	FS-1 TB-4	36SS50	36SS51	36SS52	36SS52D	36SS53	36SS54
Sample Depth:		54ft	55ft				0.5-1.5ft	0.5-1.5ft	0.5-1.5ft	0.5-1.5ft	0.5-1.5ft	0.5-1.5ft
Date Sampled:		9/27/89	10/3/89	10/1/87	10/1/87	4/24/90	9/20/95	9/20/95	9/20/95	9/20/95	9/20/95	9/20/95
Chemical	CRQL/CRDL											
Volatiles (ug/Kg)												
Methylene Chloride	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	10	ND	13	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroethane	10	ND	ND	ND	20 JB	ND	ND	ND	ND	ND	ND	ND
Semivolatiles (ug/Kg)												
bis(2-Ethylhexyl)phthalate	330	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phenanthrene	330	ND	ND	ND	ND	ND	81	100	79	96	150	ND
Anthracene	330	ND	ND	ND	ND	ND	ND	ND	ND	12	ND	ND
Fluoranthene	330	ND	ND	ND	ND	ND	75	180	140	130	140	ND
Pyrene	330	ND	ND	ND	ND	ND	110	270	230	210	220	ND
Benzo(a)anthracene	330	ND	ND	ND	ND	ND	82	90	130	110	93	ND
Chrysene	330	ND	ND	ND	ND	ND	ND	ND	180	170	240	ND
Benzo(b)fluoranthene	330	ND	ND	ND	ND	ND	ND	210	370	270	390	ND
Benzo(k)fluoranthene	330	ND	ND	ND	ND	ND	ND	180	330	250	320	ND
Benzo(a)pyrene	330	ND	ND	ND	ND	ND	ND	100	180	190	140	ND
Indeno(1,2,3-cd)pyrene	330	ND	ND	ND	ND	ND	ND	49	ND	130	79	ND
Benzo(g,h,i)perylene	330	ND	ND	ND	ND	ND	ND	44	ND	150	ND	ND
Acenaphthlene	330	ND	ND	ND	ND	ND	ND	ND	50	ND	54	ND
Pesticides (ug/Kg)												
alpha-BHC	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.23	ND
Aldrin	1.7	ND	ND	ND	ND	ND	ND	ND	ND	0.16	ND	ND
Heptachlor epoxide	1.7	ND	ND	ND	ND	ND	0.15	0.29	ND	ND	0.48	ND
Endosulfan I	1.7	ND	ND	ND	ND	ND	ND	0.6	0.74	ND	0.59	ND
Dieldrin	3.3	ND	ND	ND	ND	ND	1.9	1.5	1.8	1.8	13	0.22
4,4'-DDE	3.3	ND	ND	ND	ND	ND	2.1	ND	0.29	0.24	1	ND
Endrin	3.3	ND	ND	ND	ND	ND	0.47	0.92	0.87	0.78	1.7	ND
Endosulfan II	3.3	ND	ND	ND	ND	ND	1	1.4	0.87	ND	1.5	ND
4,4'-DDD	3.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	ND
4,4'-DDT	3.3	ND	ND	ND	ND	ND	5	0.24	0.81	1	3.2	ND
Methoxychlor	17	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.72	ND
Endrin ketone	3.3	ND	ND	ND	ND	ND	0.53	ND	ND	0.34	ND	ND
alpha-Chlordane	1.7	ND	ND	ND	ND	ND	0.24	0.16	0.24	0.19	0.35	ND
gamma-Chlordane	1.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.15	ND
Metals(mg/Kg)												
Aluminum	200	NA	NA	1090	471	400	1580	931	1790	1800	2690	811
Antimony	60	NA	NA	ND	ND	ND	ND	ND	ND	ND	0.63	ND
Arsenic	10	NA	NA	ND	ND	ND	0.67	ND	0.93	1.2	1.2	ND
Barium	200	NA	NA	ND	ND	ND	64.8 J	11.5 J	5.1 J	5.1 J	4.6 J	2.7 J
Chromium	10	NA	NA	ND	ND	ND	3	2.4	3.8	3.2	7.4	1.8
Cobalt	50	NA	NA	ND	ND	ND	0.99	0.98	0.99	1	0.87	0.7
Iron	100	NA	NA	1430	749	860	2370	1770	3370	3220	3740	2250
Lead	3	ND	ND	1.8	ND	ND	23.6	8.4	41.4	36.6	114	2.2 J
Magnesium	5000	NA	NA	ND	ND	ND	290	225	387	383	404	234
Manganese	15	NA	NA	32	21	7.8	23.6	42.4	31.5	29.7	24.9	30.6
Nickel	40	NA	NA	ND	ND	ND	1.6	1.9	2	1.9	2.7	1.4
Potassium	5000	NA	NA	ND	ND	ND	107 J	98.7 J	161	176 J	165 J	96.3 J
Sodium	5000	NA	NA	ND	ND	ND	258 J	272 J	253	258 J	255 J	235 J
Vanadium	50	NA	NA	ND	ND	ND	3.7	2.9	5.6	5.3	6.2	3.5
Zinc	20	NA	NA	6	6.1	5.7	ND	ND	ND	ND	ND	ND
Miscellaneous(mg/Kg)												
TOC	50	NA	NA	NA	NA	NA	50	NA	50	NA	NA	50
TPH	0.2	ND	15.4	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 4.2
Analytical Results from Groundwater Collected at Fuel Spill Site 1
Pre-1997

Source	CRQL	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI
Sample Location		39MW1	39MW2	39MW4	39MW4A	39MW6	39MW7	39MW8	39MW8D	39MW9	39MW9D	39MW10A	39MW10B	39MW414
Date Sampled		10/25/90	10/24/90	10/24/90	10/24/90	10/24/90	10/24/90	10/25/90	10/25/90	10/24/90	10/24/90	10/24/90	10/24/90	10/25/90
VOA (ug/L)	CRQL													
Chloromethane	1	ND	ND	ND	ND	ND	ND	ND	8	ND	ND	ND	ND	8
Methylene Chloride	2	2	ND	ND	ND	ND	ND	1	1	ND	ND	ND	ND	1
Acetone	5	40	210	ND	8	5	ND	8	13	ND	ND	ND	ND	8
2-Butanone	5	670 D	ND	ND	ND	180	ND	ND	ND	120000	161000	ND	ND	ND
4-Methyl-2-Pentanone	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	1	ND	ND	ND	ND	ND	ND	2	2	ND	ND	ND	ND	ND
Toluene	1	3 X	85 D	ND	ND	10	2500	8 X	2 X	ND	ND	ND	ND	4
Ethylbenzene	1	ND	ND	ND	ND	ND	220	ND	ND	ND	ND	ND	ND	ND
Xylene	1	1	180 D	ND	ND	4 X	400	370	170 D	ND	ND	ND	ND	1 X
Trichloroethene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromodichloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibromochloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromoform	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SVOA (ug/L)	CRQL													
Benzyl Alcohol	10	ND	ND	28	ND	ND	18	ND	ND	ND	ND	ND	ND	ND
2-Methylphenol	10	ND	34	ND	ND	ND	ND	10	10	ND	ND	ND	ND	ND
bis(2-Ethylhexyl)phthalate	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Miscellaneous (mg/L)	RL													
TPH	0.2	ND	0.34	ND	ND	ND	0.80	0.80	ND	ND	ND	ND	ND	ND
Pesticides/PCBs (ug/L)	CRQL													
4,4-DDT	0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Metals (ug/L)	CRQL													
Aluminum	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	12.3	ND
Barium	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	5000	ND	ND	ND	ND	ND	ND	8000	ND	ND	ND	ND	ND	ND
Cyanide	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cobalt	50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	25	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	100	267	10800	2740	ND	ND	12000	ND	3280	ND	ND	ND	22100	ND
Lead	5	ND	158	ND	ND	ND	80	30.2	ND	ND	ND	ND	ND	ND
Magnesium	5000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese	15	172	734	1300	ND	604	740	23.0	873	1400	1400	282	830	103
Nickel	40	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Potassium	5000	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sodium	5000	5430	5120	5520	ND	ND	5200	ND	5080	ND	ND	ND	ND	ND
Thallium	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium	50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	40	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Selenium	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Source	CRQL	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI	1991RI
Sample Location		39MWRFW11	39MW12	39MW41	39MW42	39MW112	39MW121	39MW412	39MW413	39MW416	39MW14	39MW14D	39MW11	39MW13
Date Sampled		10/25/90	10/26/90	10/25/90	10/26/90	10/26/90	10/26/90	10/25/90	10/25/90	10/25/90	11/19/90	11/19/90	11/19/90	11/19/90
VOA (ug/L)	CRQL													
Chloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	2	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	5	8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Butanone	5	190	ND	ND	1900	53000	ND	ND	ND	ND	ND	ND	ND	ND
4-Methyl-2-Pentanone	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	1	1 X	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylene	1	5 X	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chloroform	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-Trichloroethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromodichloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Dibromochloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bromoform	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SVOA (ug/L)	CRQL													
Benzyl Alcohol	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Methylphenol	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Ethylhexyl)phthalate	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	19	ND	ND	ND
Miscellaneous (mg/L)	RL													
TPH	0.2	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pesticides/PCBs (ug/L)	CRQL													
4,4-DDT	0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Metals (ug/L)	CRQL													
Aluminum	200	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic	10	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium	200	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	5000	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cyanide	10	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	10	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cobalt	50	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	25	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	100	NA	ND	ND	ND	5400	2800	ND	463	2800	1470	1100	6100	ND
Lead	5	NA	8.3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Magnesium	5000	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese	15	NA	25.0	61.8	17.7	410	884	ND	48.4	614	213	210	840	30.4
Nickel	40	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Potassium	5000	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Silver	10	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sodium	5000	NA	ND	5700	5300	ND	5240	ND	ND	5010	ND	ND	6700	6080
Thallium	10	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium	50	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	40	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Selenium	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

KEY
D = Dilution value
J = Data is estimated
E = Outside linear range
ND = Nondetect
NA = Not analyzed
X = The mass spectrum does not meet EPA CLP criteria for confirmation, but compound presence is strongly suspected
B = Analyte detected in both the sample and associated method blank
Dup = Concentration from duplicate sample
N = Spike sample recovery not within control limits

DOES NOT INCLUDE DISSOLVED INORGANIC DATA

Table 4.2
Analytical Results from Groundwater Collected at Fuel Spill Site 1
Pre-1997 (continued)

Source		1991IRI	1991IRI	1991IRI	1991IRI	1991IRI	SMOC-FS1	SMOC-FS1	SMOC-FS1	SMOC-FS1	OW Mashpee	OW Mashpee	3-3A	3-3A	3-3B	**3-3B	3-3B	3-3B	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	3-9C PH8	SEPOOU	SEPOOU	SEPOOU
Sample Location		MW-112	MW-112D	MW-4	MW-4A	FS1MW8	39MWK15131	39MWK15131D	39MWK18X98	39MWK17105	JMW518	JMW517	MW-1	MW-2	RFW-811	MW-1	MW-2	MW-4	MW-553A	MW-562B	MW-552C	MW-552D	MW-563A	MW-553D	MW-560	MW-558A	MW-559B	MW-558C	MW-557	MW-538A	MW-538B	MW-538C
Date Sampled		2/1/90	2/1/90	2/1/90	2/1/90	2/2/90	12/9/94	12/5/94	12/5/94	12/9/94	9/13/97	9/13/97	10/20/97	10/07/98	01/12/99	01/12/99	01/12/99	01/12/99	11/19/93	11/19/93	11/19/93	11/19/93	11/19/93	11/19/93	12/09/93	12/07/93	12/07/93	12/07/93	11/19/93	12/08/93	12/08/93	12/08/93
VOA (ug/L)	CRQL																															
Chloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methylene Chloride	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	25 JB-DUP	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	90	12.8	ND	ND	ND	3 BJ	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Butanone	5	750 D	88	46000 D	55000DEJ	24000 X	ND	ND	ND	ND	420	76	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Methyl-2-Pentanone	5	ND	ND	51	85	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	8.8	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND / 8.4 J	0.3 J	ND
Toluene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.15	0.03	ND	1800	7 BJ	ND	ND	ND	0.2 J	ND	ND	ND	0.5 J	ND	0.8 J	0.5 J	2	ND	ND	ND	3	0.3 J
Ethylbenzene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	400	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.7 J	ND
Trichloroethene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4 J	1 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	1 J	ND
Chloroform	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2	2	3	0.2 J	0.2 J	3	ND	ND	ND	0.3 J	4 J
1,1,1-Trichloroethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.8 J	ND	ND	ND	0.4 J	ND
Bromodichloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.2 J	ND	ND	ND	0.4 J	ND
Dibromochloromethane	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5 J	ND	ND	ND	0.6 J	ND
Bromoform	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4 J	ND	ND	ND	0.7 J	ND
Benzene	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.8 J	ND	ND	ND	ND	ND
SVOA (ug/L)	CRQL																															
Benzyl Alcohol	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-Methylphenol	10	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	ND	ND	ND	ND	24	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
bis(2-Ethylhexyl)phthalate	10	ND	ND	ND	10	ND	2 J	ND	ND	ND	NA	NA	ND	ND	ND	ND	ND	2J	2J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Miscellaneous (mg/L)	RL																															
TPH	0.2	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pesticides/PCBs (ug/L)	CRQL																															
4,4'-DDT	0.1	NA	NA	NA	NA	NA	0.0045 J	ND	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Metals (ug/L)	CRQL																															
Aluminum	200	NA	NA	NA	NA	NA	2580 J	1720	3320	ND	ND	ND	ND	ND	NA	NA	NA	NA	ND	447 / 180 J	230	37.3 J	ND	1210	87.1 J	78.4 J	4240	130 J	3660	181 J / 731	ND	ND
Arsenic	10	NA	NA	NA	NA	NA	ND	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	2.8 J	ND	ND	2.8 J	ND	3 J	ND	ND	ND
Barium	200	NA	NA	NA	NA	NA	10.2 J	13.6	28.8	8.8	NA	NA	ND	ND	NA	NA	NA	NA	ND	6.8 J / 3.2 J	2.5 J	14.5 J	ND	22.7 J	13.4 J	3 J	40.2 J	24.8 J	10 J	ND	20.1 J	10.4 J
Calcium	5000	NA	NA	NA	NA	NA	5740	5710	2040	8880	ND	ND	ND	ND	NA	NA	NA	NA	2900 J	3020 J / 2000 J	2040 J	ND	ND	1300 J	1340 J	4200 J	1800 J	1900 J	6040	3950 J / 4040 J	2020 J	ND
Cyanide	10	NA	NA	NA	NA	NA	NA	NA	NA	NA	14	ND	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chromium	10	NA	NA	NA	NA	NA	17.2	8.1	31.8	2.4	NA	NA	ND	ND	NA	NA	NA	NA	ND	6.4 J	ND	ND	ND	8.8 J	ND	ND	41.3	ND	10.4 J	ND	ND	ND
Cobalt	50	NA	NA	NA	NA	NA	2.1	1.7	4.8	3.8	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	3.4 J	ND	ND	5.4 J	ND	3.3 J	ND	ND	ND
Copper	25	NA	NA	NA	NA	NA	4.4	3.8	14.4	1.4	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	10.2 J	ND	ND	ND	ND	ND
Iron	100	NA	NA	NA	NA	NA	2030	2080	5800	980	ND	222	ND	18400	NA	NA	NA	NA	ND	881 / 300	561	ND	ND	2300	ND	ND	8880	ND	6010	ND / 440 J	ND	ND
Lead	5	ND	ND	ND	ND	ND	6.6	8.8	3.5	2.8	NA	NA	16	71	ND	ND	128 N	ND	ND	4.3	4.8	ND	3 J	4	ND	ND	4.2 J	ND	4.2	ND	ND	ND
Magnesium	5000	NA	NA	NA	NA	NA	2100	2040	2020	4740	ND	ND	ND	ND	NA	NA	NA	NA	1330 J	1080 J / 1070 J	1980 J	1240 J	684 J	1440 J	1300 J	1780 J	2980 J	2500 J	2880 J	2070 J / 2130 J	2050 J	1820 J
Manganese	15	NA	NA	NA	NA	NA	141	130	436	206	36	88	700	711	NA	NA	NA	NA	ND	107 / 88.5	82	40.1	2.2 J	500	807	ND	105	20.7	80.4	22.1 / 25.8	815	32.1
Nickel	40	NA	NA	NA	NA	NA	10	10.2	22.2	6.1	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	22.2 J	ND	ND	ND	ND	ND
Potassium	5000	NA	NA	NA	NA	NA	1870	1770	1600	1300	NA	NA	ND	ND	NA	NA	NA	NA	730 J	883 J / 800 J	837 J	873 J	486 J	880 J	1020 J	787 J	1730 J	840 J	1410 J	737 J / 712 J	1330 J	740 J
Silver	10	NA	NA	NA	NA	NA	ND	6.8	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sodium	5000	NA	NA	NA	NA	NA	10000	13400	5300	7000	8020	10400	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Thallium	10	NA	NA	NA	NA	NA	3.1	ND	ND	ND	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.1 J	ND	ND	ND
Vanadium	50	NA	NA	NA	NA	NA	4.6	3.4	8.8	ND	NA	NA	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	4.1 J	ND	ND	14.3 J	ND	13 J	ND	ND	ND
Zinc	40	NA	NA	NA	NA	NA	23 J	24.2 J	22.4 J	25.8 J	30	41	ND	23-DUP	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cadmium	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	ND	ND	3.1 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Selenium	5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA	NA	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND / 2.4 J	ND	ND

KEY:
D = Dilution value
J = Data is estimated
E = Outside linear range
ND = Nondetect
NA = Not analyzed
X = The mass spectrum does not meet EPA CLP criteria for confirmation, but compound presence is strongly suspected
B = Analyte detected in both the sample and associated method blank
Dup = Concentration from duplicate sample
N = Spike sample recovery not within control limits

Table 4.3
Analytical Results from Groundwater Collected at Fuel Spill Site 1,
February 1997, October 1997, and April 1998

Monitoring Well	MW16	MW16Dup	MW17	MW131A	MW131B	MW131C	MW132A	MW132ADup	MW132B	MW132BDup	MW132C	MW133	MW135
Volatile Organics (ug/L)													
Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon disulfide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	0.25 J	ND	ND	ND	0.54 J	0.48 J	0.55 J	ND	ND
4-Methyl-2-pentanone	ND	ND	ND	ND	ND	0.21 J	ND	ND	ND	0.22 J	ND	ND	ND
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.33 J	ND	ND
Benzene	ND	ND	0.14 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene	ND	ND	0.16 J	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dibromoethane	ND	ND	ND	2.7	3.4	0.58	2.2	2.2	7.7	7.2	6.5	ND	ND
Xylenes (total)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total Metals (ug/L)													
Aluminum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND	ND	ND	ND	20.5	ND	1.5 J	ND	1.6 J	1.3 J
Barium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	2130 J	2070 J	4810 J	6830	6770	3890	7820	7850	8310	8420	6280	5730	3380
Chromium	ND	ND	ND	ND	ND	ND	6.4	ND	ND	ND	ND	ND	ND
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	207	169	120	132	ND	ND	571	329	127	987	ND	ND	1060
Lead	1.7 J	1.4 J	ND	22.7	1.2	1.6	3	2.6	2.4	2.6	2.2	3.7	ND
Magnesium	2280 J	3180 J	3180 J	3180 J	2160 J	1360 J	2400	2310	3090 J	3220 J	2500 J	3100 J	1770 J
Manganese	14.8 J	304	304	304	26.2	8.8	225	218	90.6	90.6	15.4	551	78.9
Mercury	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Potassium	562 J	598 J	1820 J	1820	ND	ND	1330	ND	ND	1240	ND	1670	2450
Sodium	5850 J	5800	6250	10400	6730	8130	9600	9270	10100	10200	8110	7520	11300
Thallium	1.3 J	1.3 J	1.3 J	1.3 J	ND	ND	ND	ND	ND	1.1 J	1.2 J	ND	ND
Vanadium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
* 1,2-Dibromoethane (EDB or ethylene dibromide) was analyzed reported from the Method 504 result
J = Data is estimated.
ND = Nondetect
NA = Not analyzed
Dup = Concentration from duplicate sample
ug/L = micrograms per liter

Table 4.3
Analytical Results from Groundwater Collected at Fuel Spill Site 1,
February 1997, October 1997, and April 1998

Monitoring Well	MW136	MW137	MW138	MW139	MW140	MW141	MW142	MW143	MW501	MW503A	MW503B	MW503C	MW504
Volatile Organics (ug/L)													
Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon disulfide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Methyl-2-pentanone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.15 J	ND	ND	ND
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dibromoethene	0.18	0.63	ND	ND	ND	ND	ND	ND	ND	2 J	0.18 J	0.11	ND
Xylenes (total)	ND	ND	ND	ND	ND	ND	ND	ND	0.16 J	0.36 J	0.3 J	0.31 J	0.43 J
Total Metals (ug/L)													
Aluminum	ND	ND	ND	ND	478	560	ND	958	ND	ND	ND	ND	208
Arsenic	ND	ND	ND	ND	1.5 J	4.5	5.3	5.3	ND	ND	ND	ND	ND
Barium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	8720	9370	8290	4780	7290	8490	18000	3600	3200	8630	5220	3778	5350
Chromium	ND	ND	ND	9.9	13.8	13.8	ND	ND	9.6	8.7	8.1	ND	12.8
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	120	ND	158	128	2880	1850	ND	3890	160	241	243	238	[illegible]
Lead	1.4	1.7	1.7	2.8	1.1	1.1	ND	1.4	ND	ND	ND	ND	ND
Magnesium	3980	2890 J	3250 J	1850 J	4200 J	2340	1720	2270	1430	2420	2300	1850	2140
Manganese	380	242	271	114	403	855	85.8	235	21.8 J	272 J	273 J	82.7	183 J
Mercury	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	ND	8.4	8.4	8	8.4	ND	ND	ND	4.7	8.8	8.2	ND	13.3
Potassium	2030	1810	1880	ND	1730	1360	2230	3010	818	1130	985	786	1180
Sodium	11500	11000	10200	8240	10300	8580	8110	17500	7140	8570	8830	5360	8130
Thallium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND	ND	ND	ND	80.7	ND	ND	ND

Notes:
* 1,2-Dibromoethene (EDB or ethylene dibromide) was analyzed reported from the Method 504 result
J = Data is estimated.
ND = Nondetect
NA = Not analyzed
Dup = Concentration from duplicate sample
ug/L = micrograms per liter

Table 4.3
Analytical Results from Groundwater Collected at Fuel Spill Site 1,
February 1997, October 1997, and April 1998

Monitoring Well	MW516A	MW516B	MW516BDup	MW516C	MW516E	MW552A	MW552B	MW552C	MW552D	MW601	MW603A	MW603D	MW603DDup
Volatile Organics (ug/L)													
Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.13 J	ND	ND
Acetone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Carbon disulfide	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.73 J	ND	ND
4-Methyl-2-pentanone	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.12 J	ND	ND
Trichloroethene	ND	ND	ND	ND	ND	ND	0.22 J	0.44 J	ND	ND	ND	ND	ND
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dibromoethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.038	7 J	0.018	0.019
Xylenes (total)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.19 J	0.38 J	0.11 J	0.11 J
Total Metals (ug/L)	ug/L												
Aluminum	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium	25.2 J	ND	ND	ND	20.6 J	ND	ND	ND	25.2	ND	ND	ND	ND
Calcium	1290 J	3010 J	3080 J	2450 J	3820 J	2900 J	3000 J	3000 J	1140 J	5280	6010	2870	2990
Chromium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	18.9
Iron	ND	ND	ND	ND	ND	ND	ND	ND	ND	172	238	182	173
Lead	ND	ND	ND	ND	3.7	ND	2.7 J	ND	1.7 J	ND	ND	ND	ND
Magnesium	1930 J	2560 J	2600 J	2950 J	525 J	1830 J	1050 J	1650 J	1720 J	1380	2420	2050	2810
Manganese	ND	ND	ND	ND	44.9	ND	8.7 J	ND	45.9	214	188 J	525 J	548 J
Mercury	ND	ND	ND	1	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	ND	ND	ND	ND	ND	ND	ND	ND	4.9 J	ND	8.3	ND	ND
Potassium	398 J	511 J	478 J	850 J	614 J	889 J	720 J	701 J	1000 J	828	1050	800	885
Sodium	5630	3810 J	3800 J	4030 J	10100 J	10500 J	9180 J	8550 J	7620 J	6860	8180	3850	4180
Thallium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0
Vanadium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND	ND	ND	ND	80.2	113	ND	ND

Notes:
* 1,2-Dibromoethane (EDB or ethylene dibromide) was analyzed reported from the Method 504 result
J = Data is estimated.
ND = Nondetect
NA = Not analyzed
Dup = Concentration from duplicate sample
ug/L = micrograms per liter

Table 4.3
Analytical Results from Groundwater Collected at Fuel Spill Site 1,
February 1997, October 1997, and April 1998

Monitoring Well	MW604	MW653	MW654	MW701	MW702	MW703	MW704	MW704Dup	MW705
Volatile Organics (ug/L)									
Chloromethane	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acetone	ND	ND	ND	ND	130 J	ND	110 J	100 J	ND
Carbon disulfide	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-Methyl-2-pentanone	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-Dibromoethane	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylenes (total)	0.13 J	0.16 J	0.13 J	0.3 J	0.16 J	0.15 J	0.28 J	0.28 J	0.15 J
Total Metals (ug/L)		ug/L							
Aluminum	ND	ND	ND	566	500	ND	ND	ND	380
Arsenic	ND	ND	ND	2.8	1.6	1.5	1.8	1.1	2.8
Barium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Calcium	3490	3840	3170	8120	4150	4020	5400	5800	8290
Chromium	ND	ND	ND	11.2	7.2	ND	8.4	ND	13.8
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	ND	138	180	1590	948	188	881	832	748
Lead	ND	ND	ND	ND	ND	ND		ND	ND
Magnesium	1680	1690	1200	2590	1720	1180	1740	1840	2340
Manganese	86.5	42.8 J	84.2	518 J	182 J	70.7 J	189 J	203 J	388 J
Mercury	ND	ND *	ND		ND	ND	ND	ND	ND
Nickel	ND	5.1	ND	8.8	4.9	ND	7.2	4.4	4.8
Potassium	772	1030	1180	1850	1190	820	1220	1250	1880
Sodium	6080	8810	6240	9050	7060	7020	7130	7480	7890
Thallium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Vanadium	ND	ND	ND	ND	2	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
* 1,2-Dibromoethane (EDB or ethylene dibromide) was analyzed reported from the Method 504 result
J = Data is estimated.
ND = Nondetect
NA = Not analyzed
Dup = Concentration from duplicate sample
ug/L = micrograms per liter

Table 4.4
Analytical Results from Surface Water Collected Downgradient of Fuel Spill Site 1, August 1997 through May 1998

August-September 1997 Event

Location:	36SW0001	36SW0002	36SW003	36SW004	36SW005	36SW006	36SW007	36SW008	36SW009	36SW010	36SW011	36SW012
Sample No:	36SW0001-01	36SW0002-01	36SW003-01	36SW004-01	36SW005-01	36SW006-01	36SW007-01	36SW008-01	36SW009-01	36SW010-01	36SW011-01	36SW012-01
Sample Date:	8/26/97	8/26/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97
Compound:	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
ETHYLENE DIBROMIDE	0.0421	0.0346	ND	ND	ND	ND	ND	ND	ND	ND	0.0378	0.0387

February-April 1998 Event

Location:	36SW0001		36SW0003				36SW0007			36SW010		
Sample No:	36SW0001-02		36SW0003-02				36SW0007-02			36SW010-02		
Sample Date:	4/29/98		4/29/98				4/29/98			4/29/98		
Compound:	ug/L		ug/L				ug/L					
ETHYLENE DIBROMIDE	0.041	NA	ND	NA	NA	NA	ND	NA	NA	0.064	NA	NA

May 1998 Event

Location:		36SW0002					36SW0007					36SW012
Sample No:		36SW0002-02					36SW0007-03					36SW012-02
Sample Date:		5/7/98					5/7/98					5/7/98
Compound:		ug/L					ug/L					ug/L
ETHYLENE DIBROMIDE	NA	0.104	NA	NA	NA	NA	ND	NA	NA	NA	NA	0.011
Analyte:												
ALUMINUM	NA	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	ND
BORON	NA	ND	NA	NA	NA	NA	52.0	NA	NA	NA	NA	ND
BARIUM	NA	7.71 J	NA	NA	NA	NA	15.3 J	NA	NA	NA	NA	22.9
CALCIUM	NA	2570	NA	NA	NA	NA	774.	NA	NA	NA	NA	2930
CADMIUM	NA	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	ND
CHROMIUM	NA	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	ND
COPPER	NA	ND	NA	NA	NA	NA	1.36 J	NA	NA	NA	NA	ND
IRON	NA	340.	NA	NA	NA	NA	41.0 J	NA	NA	NA	NA	174.
POTASSIUM	NA	802.	NA	NA	NA	NA	ND	NA	NA	NA	NA	874.
MAGNESIUM	NA	1700	NA	NA	NA	NA	801.	NA	NA	NA	NA	2060
MANGANESE	NA	14.9	NA	NA	NA	NA	15.5	NA	NA	NA	NA	ND
SODIUM	NA	6500	NA	NA	NA	NA	5090	NA	NA	NA	NA	6190
LEAD	NA	ND	NA	NA	NA	NA	ND	NA	NA	NA	NA	ND

Notes:
NA - not analyzed
ND - not detected
ug/L - micrograms per liter
J - estimated result

Table 4.4
Analytical Results from Surface Water Collected Downgradient of Fuel Spill Site 1, August 1997 through May 1998

August-September 1997 Event

Location:	36SW013	36SW0014	36SW0015	36SW0016	36SW0017	36SW0018	36SW0019	36SW0020	36SW0021	36SW0022	36SW0023
Sample No	36SW013-01	36SW0014-01	36SW0015-01	36SW0016-01	36SW0017-01	36SW0018-01	36SW0019-01	36SW0020-01	36SW0021-01	36SW0022-01	36SW0023-01
Sample Date	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/27/97	8/26/97	8/26/97
Compound:	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
ETHYLENE DIBROMIDE	ND	0.0301	ND	0.937	1.43	0.868	0.0434	0.0451	0.0492	0.031	0.0256

February-April 1998 Event

Location:	36SW013		36SW0015	36SW0016	36SW0017	36SW0018	36SW0019	36SW0020	36SW0021		
Sample No:	36SW013-02		36SW0015-02	36SW0016-02	36SW0017-02	36SW0018-02	36SW0019-02	36SW0020-02	36SW0021-02		
Sample Date:	4/29/98		4/29/98	2/11/98	2/11/98	2/11/98	2/11/98	2/11/98	2/11/98		
Compound:	ug/L		ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L		
ETHYLENE DIBROMIDE	ND	NA	ND	0.06	0.18	0.061	ND	ND	ND	NA	NA

May 1998 Event

Location:				36SW0016	36SW0017	36SW0018		36SW0020			
Sample No:				36SW0016-03	36SW0017-03	36SW0018-03		36SW0020-03			
Sample Date:				5/7/98	5/7/98	5/7/98		5/7/98			
Compound:				ug/L	ug/L	ug/L		ug/L			
ETHYLENE DIBROMIDE	NA	NA	NA	1.23	1.15	0.022	NA	0.035	NA	NA	NA
Analyte:											
ALUMINUM	NA	NA	NA	ND	338.	187.	NA	174.	NA	NA	NA
BORON	NA	NA	NA	ND	ND	70.8	NA	57.4	NA	NA	NA
BARIUM	NA	NA	NA	3.86 J	6.97 J	10.8 J	NA	22.4	NA	NA	NA
CALCIUM	NA	NA	NA	3910	3010	1210	NA	2890	NA	NA	NA
CADMIUM	NA	NA	NA	ND	ND	ND	NA	ND	NA	NA	NA
CHROMIUM	NA	NA	NA	ND	0.700 J	0.700 J	NA	ND	NA	NA	NA
COPPER	NA	NA	NA	1.24 J	2.43 J	2.11 J	NA	1.70 J	NA	NA	NA
IRON	NA	NA	NA	368.	765.	211.	NA	1480	NA	NA	NA
POTASSIUM	NA	NA	NA	787.	897.	825. J	NA	1030	NA	NA	NA
MAGNESIUM	NA	NA	NA	1790	1520	1070	NA	1800	NA	NA	NA
MANGANESE	NA	NA	NA	ND	25.4	11.8	NA	47.8	NA	NA	NA
SODIUM	NA	NA	NA	7030	6890	5740	NA	7820	NA	NA	NA
LEAD	NA	NA	NA	ND	2.02	ND	NA	ND	NA	NA	NA

Notes:
NA - not analyzed
ND - not detected
ug/L - micrograms per liter
J - estimated result

Table 4.4
Analytical Results from Surface Water Collected Downgradient of Fuel Spill Site 1, August 1997 through May 1998

August-September 1997 Event

Location: Sample No: Sample Date: Compound:	36SW0024 36SW0024-01 9/4/97 ug/L	36SW0025 36SW0025-01 9/4/97 ug/L						36SW0101 36SW0101-01 9/4/97 ug/L	36SW0102 36SW0102-01 9/4/97 ug/L	36SW0103 36SW0103-01 9/4/97 ug/L
ETHYLENE DIBROMIDE	0.0335	0.0168	NA	NA	NA	NA	NA	ND	ND	ND

February-April 1998 Event

Location: Sample No: Sample Date: Compound:			36SW0026 36SW0026-01 2/11/98 ug/L	36SW0027 36SW0027-01 2/11/98 ug/L	36SW0028 36SW0028-01 2/11/98 ug/L	36SW0029 36SW0029-01 2/11/98 ug/L	36SW0036 36SW0036-01 4/29/98 ug/L			
ETHYLENE DIBROMIDE	NA	NA	0.025	ND	ND	ND	ND	NA	NA	NA

May 1998 Event

Location: Sample No: Sample Date: Compound:										
ETHYLENE DIBROMIDE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Analyte:										
ALUMINUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BORON	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
BARIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CALCIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CADMIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
CHROMIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
COPPER	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
IRON	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
POTASSIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MAGNESIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MANGANESE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SODIUM	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LEAD	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Notes:
- NA - not analyzed
- ND - not detected
- ug/L - micrograms per liter
- J - estimated result

Tab.)

Analytical Results for Sediment Collected Downgradient of Fuel Spill Site 1,
May 1998

Location:	36SW002	36SW007	36SW007	36SW012	36SW016	36SW017	36SW018	36SW020
Sample No:	36SE002-02	36SE007-03	36SE007-03FD	36SE012-02	36SE016-03	36SE017-03	36SE018-03	36SEW020-03
Matrix:	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment	Sediment
Sample Date:	07-May-98	07-May-98	07-May-98	07-May-98	07-May-98	07-May-98	07-May-98	07-May-98
Volatile Organics (ug/Kg)								
ETHYLENE DIBROMIDE	ND	ND	ND	ND	ND	ND	0.075	ND
Metals (mg/Kg):								
ALUMINUM	693	466 J	3090 J	1120	1200	691	503	729 J
ARSENIC	ND	ND	0.433 J	ND	ND	ND	ND	0.684 J
BARIUM	2.04 J	1.74 J	2.12 J	3.78 J	3.61 J	3.73 J	3.02 J	2.96 J
BERYLLIUM	0.0674 J	0.0812 J	0.0847 J	0.0561 J	ND	0.0848 J	0.0406 J	0.0686 J
CALCIUM	ND	74.6 J	500 J	88.6 J	500 J	123 J	331 J	68 J
COBALT	0.204 J	ND	1.16 J	0.226 J	ND	ND	ND	0.47 J
CHROMIUM	1.37 J	2.9	2.67	1.71 J	1.79 J	2.18 J	4.74	1.57 J
COPPER	1.02 J	0.456 J	0.881 J	ND	4.14 J	1.28 J	0.505 J	ND
IRON	1550	1470 J	7020 J	1310	1920	2080	1060	2090
POTASSIUM	ND	ND	ND	ND	ND	ND	ND	139 J
MAGNESIUM	163 J	76.4 J	1290	173 J	177 J	111 J	112 J	196 J
MANGANESE	17	7.58 J	83.4 J	8.11	21.4	9.21	8.1	15.8
SODIUM	90.7 J	126 J	112 J	257 J	101 J	72.5 J	103 J	84.3 J
NICKEL	0.486 J	ND	0.6 J	0.491 J	0.225 J	0.384 J	0.462 J	0.432 J
LEAD	ND	2.59	1.9	3.38	8.9	4.57	3.71	2.1
SELENIUM	ND	ND	0.318 J	ND	ND	ND	ND	ND
VANADIUM	2.29 J	2.77 J	10.2	2.63 J	3.59 J	4.1 J	ND	4.11 J
ZINC	2.47 J	1.55 J	8.09	3.86	3.56 J	2.57 J	1.45 J	4.09

Notes:
ND - not detected
ug/Kg - micrograms per kilogram
mg/Kg - milligrams per kilogram
J - estimated result

Drive Poi ata
Quashnet River Bogs

Matrix	Analyte	Location	Date	Depth	Result	Detection Limit	Reporting Limits	Units	Qual
WG	1,1,1-TRICHLOROETHANE	36DP0014	6/4/98	4.5	2.93		1	UG/L	
WS	1,2-DIBROMOETHANE (EDB)	36DP0030	6/19/98	50.8	0.005	0.005	0.01	UG/L	J
WG	1,2-DIBROMOETHANE (EDB)	36DP0009	6/2/98	4	0.013	0.005	0.01	UG/L	
WG	1,2-DIBROMOETHANE (EDB)	36DP0005	6/3/98	6.5	0.017	0.005	0.01	UG/L	
WS	1,2-DIBROMOETHANE (EDB)	36DP0023	6/4/98	5	0.027	0.005	0.01	UG/L	
WS	1,2-DIBROMOETHANE (EDB)	36DP0032	6/22/98	24.2	0.117	0.005	0.01	UG/L	
WG	1,2-DIBROMOETHANE (EDB)	36DP0004	6/2/98	6.5	0.163	0.005	0.01	UG/L	
WG	1,2-DIBROMOETHANE (EDB)	36DP0016	6/3/98	4.5	0.34	0.025	0.05	UG/L	
WG	1,2-DIBROMOETHANE (EDB)	36DP0020	6/3/98	4.5	1.38	0.05	0.1	UG/L	
WS	1,2-DIBROMOETHANE (EDB)	36DP0029	6/19/98	16.5	1.38	0.005	0.1	UG/L	
WG	1,2-DIBROMOETHANE (EDB)	36DP0018	6/3/98	4.5	1.44	0.05	0.1	UG/L	
WS	1,2-DIBROMOETHANE (EDB)	36DP0026	6/18/98	22.9	1.45	0.005	0.01	UG/L	
WS	1,2-DIBROMOETHANE (EDB)	36DP0022	6/4/98	5	5.45	0.25	0.5	UG/L	
WG	TETRACHLOROETHYLENE(PCE)	36DP0018	6/3/98	4.5	0.184	0.154	1	UG/L	J
WS	TOLUENE	36DP0032	6/22/98	24.2	0.347	0.337	1	UG/L	J
WS	TRICHLOROETHYLENE (TCE)	36DP0033	6/22/98	28.1	1	0.329	1	UG/L	
WS	TRICHLOROETHYLENE (TCE)	36DP0030	6/19/98	50.8	2.05	0.329	1	UG/L	

after data supplied by Jacobs Engineering

PRELIMINARY DATA

	36MW0062	36MW0004	36MW0007	36MW0065	36MW0069	36MW0108	36MW0412	36MW0413	36MW0413 FD	36MW0415
Date Sampled	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/23/99	4/23/99	4/23/99	4/23/99
EDB (method E504.1)										
1,2-DIBROMO-3-CHLOROPROPANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DIBROMOETHANE (EDB)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Metals (method ILM04.1)										
ALUMINUM (TOTAL)	47.2 J	42.1 J	35.7 J	43 J	52 J	74.4 J	60 J	58.6 J	43.1 J	44.4 J
ANTIMONY (TOTAL)	6.1	ND	ND	3.5 J	7.1	ND	ND	ND	4.6 J	ND
ARSENIC (TOTAL)	4.5 J	ND	2.2 J	ND	ND	22.7	ND	ND	ND	ND
BARIUM (TOTAL)	20.2	22.5	42.2	57.6	38	21.2	11 J	20	20.9	21.2
BERYLLIUM (TOTAL)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CADMIUM (TOTAL)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CALCIUM (TOTAL)	1630	1430	2860	2070	2680	1110	1340	1280	971	968
CHROMIUM (TOTAL)	ND	ND	ND	ND	ND	ND	1.6 J	ND	ND	ND
COBALT (TOTAL)	2.8 J	9.9	2.4 J	3.6 J	0.98 J	12.2	ND	1.1 J	1.2 J	1 J
COPPER (TOTAL)	2.5 J	ND	ND	ND	0.96 J	ND	ND	ND	ND	ND
IRON (TOTAL)	5860	ND	5920	2060	32.5 J	22100	ND	158	624	503
LEAD (TOTAL)	31.6	ND	39.2	16.6	ND	ND	ND	ND	ND	ND
MAGNESIUM (TOTAL)	664	1700	768	1070	1660	892	623	768	778	774
MANGANESE (TOTAL)	230	638	264	60.9	331	664	5.5 J	47.4	6.9 J	7 J
NICKEL (TOTAL)	ND	1.7 J	2.2 J	6 J	ND	3 J	2.8 J	1.8 J	ND	ND
POTASSIUM (TOTAL)	763 J	901 J	1290 J	ND	1220 J	1500	ND	763 J	1230 J	1100 J
SELENIUM (TOTAL)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SILVER (TOTAL)	ND	1.2 J	ND	ND	ND	ND	2.2 J	2 J	ND	ND
SODIUM (TOTAL)	4340	6150	6160	4890	8770	6470	4170	6060	4620	4665
THALLIUM (TOTAL)	7.7 J	4.3 J	ND	3.6 J	4 J	ND	6.4 J	3.5 J	6 J	2.9 J
VANADIUM (TOTAL)	1.1 J	ND	ND	ND	ND	1.2 J	ND	ND	ND	ND
ZINC (TOTAL)	34.6	7.4 J	13.9 J	43.2	30.1	14.6 J	11.7 J	14.2 J	10 J	10.9 J
MERCURY (TOTAL)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

PRELIMINARY DATA

	35MW0002	35MW0004	35MW0007	35MW0008	35MW0009	35MW0010B	35MW0412	35MW0413	35MW0413 FD	35MW0415
Date Sampled	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/23/99	4/23/99	4/23/99	4/23/99
ACENAPHTHYLENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ANTHRACENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZO(A)ANTHRACENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZO(A)PYRENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZO(B)FLUORANTHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZO(G,H,I)PERYLENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZO(K)FLUORANTHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZYL BUTYL PHTHALATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS(2-CHLOROETHOXY) METHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS(2-CHLOROETHYL) ETHER (2-CHLORO	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BIS(2-ETHYLHEXYL) PHTHALATE	ND	ND	1.8 J	ND	ND	ND	ND	ND	2.0 J	ND
CHRYSENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DI-N-BUTYL PHTHALATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DI-N-OCTYLPHTHALATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DIBENZ(A,H)ANTHRACENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DIBENZOFURAN	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DIETHYL PHTHALATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DIMETHYL PHTHALATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FLUORANTHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
FLUORENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HEXACHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HEXACHLOROBUTADIENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HEXACHLOROCYCLOPENTADIENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HEXACHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
INDENO(1,2,3-C,D)PYRENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ISOPHORONE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-NITROSODI-N-PROPYLAMINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
N-NITROSODIPHENYLAMINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NAPHTHALENE	1.2 J	ND	1.2 J	ND	ND	ND	ND	ND	ND	ND
NITROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PENTACHLOROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PHENANTHRENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
PYRENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

FS-1 Source Area
Groundwater Sampling

PRELIMINARY DATA

38S185-01

	3SGMW0002	3SGMW0004	3SGMW0007	3SGMW0005	3SGMW0009	3SGMW0010B	3SGMW0412	3SGMW0413	3SGMW0413 FD	3SGMW0415
Date Sampled	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/23/99	4/23/99	4/23/99	4/23/99
TERT-BUTYL METHYL ETHER	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TETRACHLOROETHYLENE(PCE)	ND	ND	ND	1.5 J	ND	ND	ND	ND	ND	ND
TOLUENE	2600	ND	76	ND	ND	ND	ND	ND	ND	ND
TRANS-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRANS-1,3-DICHLOROPROPENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHYLENE (TCE)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
XYLENES, TOTAL	1300	ND	900	130	ND	ND	ND	ND	ND	ND
SVOCs (method OLC 02.1)										
2,2'-OXYBIS(1-CHLORO)PROPANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4,5-TRICHLOROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4,6-TRICHLOROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-DICHLOROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-DIMETHYLPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-DINITROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,4-DINITROTOLUENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2,6-DINITROTOLUENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-CHLORONAPHTHALENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-CHLOROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-METHYLNAPHTHALENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-METHYLPHENOL (O-CRESOL)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-NITROANILINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-NITROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3,3'-DICHLOROBENZIDINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3-NITROANILINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,6-DINITRO-2-METHYLPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-BROMOPHENYL PHENYL ETHER	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-CHLORO-3-METHYLPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-CHLOROANILINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-CHLOROPHENYL PHENYL ETHER	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-METHYLPHENOL (P-CRESOL)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-NITROANILINE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4-NITROPHENOL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ACENAPHTHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

PRELIMINARY DATA

	36MW0002	36MW0004	36MW0007	36MW0008	36MW0005	36MW0010B	36MW0412	36MW0413	36MW0413 FD	36MW0415
Date Sampled	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/22/99	4/23/99	4/23/99	4/23/99	4/23/99
VOCs (method OLC02.1)										
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,2,2-TETRACHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,2-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2,4-TRICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DIBROMO-3-CHLOROPROPANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DIBROMOETHANE (EDB)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROPROPANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-HEXANONE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ACETONE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BROMOCHLOROMETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BROMODICHLOROMETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BROMOFORM	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BROMOMETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON DISULFIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROFORM	ND	0.97 J	ND	6	7.6	0.55 J	ND	ND	ND	ND
CHLOROMETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CIS-1,2-DICHLOROETHYLENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CIS-1,3-DICHLOROPROPENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DIBROMOCHLOROMETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ETHYLBENZENE	200	ND	160	[illegible]	ND	ND	ND	ND	ND	ND
METHYL ETHYL KETONE (2-BUTANONE)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
METHYL ISOBUTYL KETONE (4-METHYL-2-	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
METHYLENE CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
STYRENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE (AFCEE)

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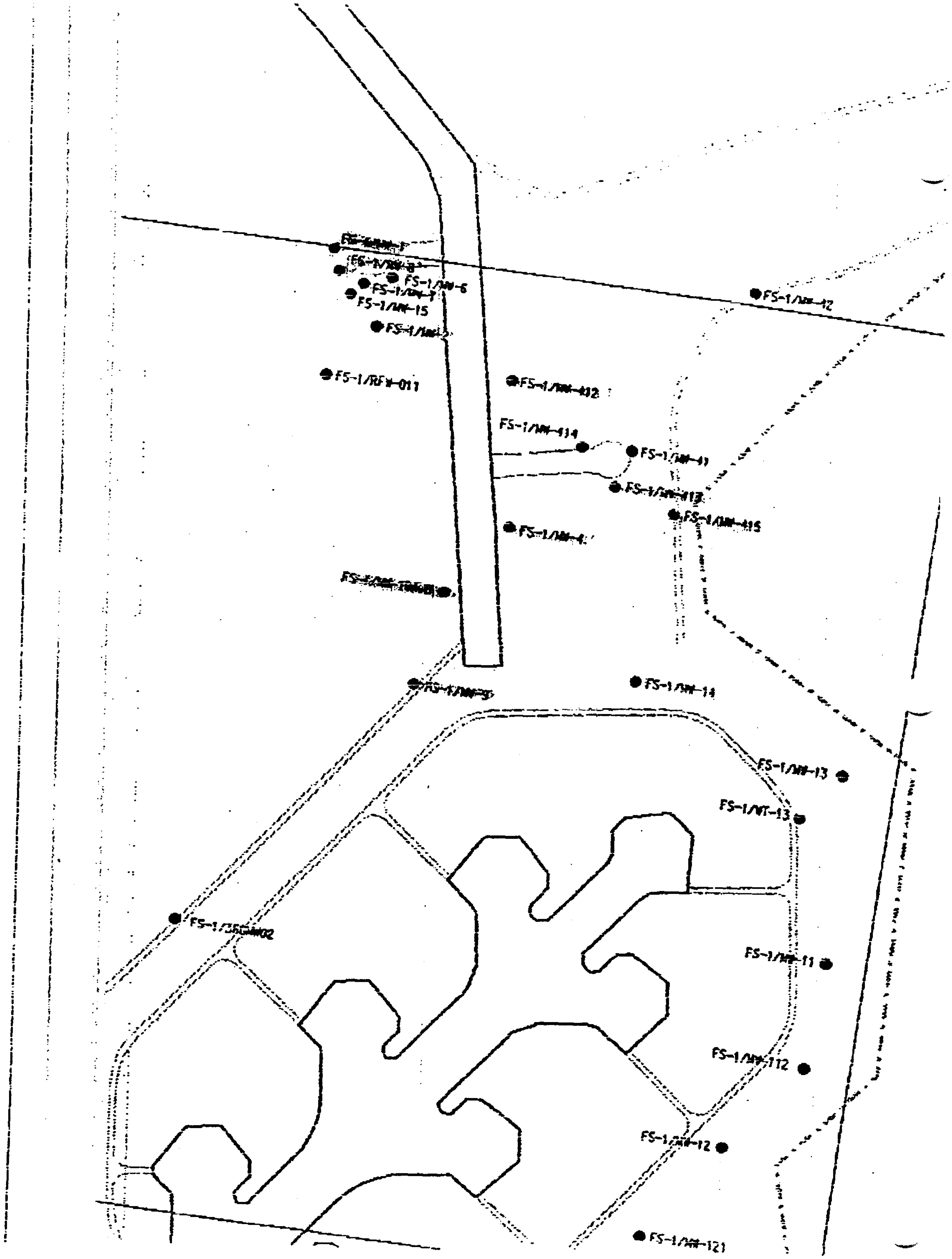
FS-1/MW-6
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FS-1/MW-42
FS-1/RFW-011
FS-1/MW-412
FS-1/MW-414
FS-1/MW-41
FS-1/MW-413
FS-1/MW-415
FS-1/MW-14
FS-1/MW-13
FS-1/WT-13
FS-1/MW-11
FS-1/MW-112
FS-1/MW-12
FS-1/MW-121

APPENDIX E

EXCERPTS FROM QUASHNET RIVER BOGS PILOT TEST

3.0 PILOT TEST SYSTEM DESCRIPTION

This section presents a description of the pilot test system. It describes the design basis as well as identifies the primary materials and methods that will be used for construction. The pilot test includes deep and shallow groundwater extraction, treatment using granular activated carbon, discharge of the treated water to adjacent surface water bodies and shallow re-injection, and earthen berms to separate the developed cranberry bogs.

Assumptions utilized in designing the pilot test system included:

1) Western tributary from the K1 must have non-detectable concentrations of EDB and the flow must be maintained within the K1 bog,
2) Brook trout spawning habitat in the K1 bog must be maintained by limiting the impacts to the groundwater hydraulics and sustaining a high dissolved oxygen content and low water temperature
3) Capturing and treating the EDB contaminated groundwater before upwelling into the bogs.

Section 4 provides the installation and startup procedures for the pilot test and a schedule for implementation and evaluation of the test. Detailed site plans are provided in Appendix C.

3.1 GROUNDWATER EXTRACTION

Contaminated groundwater will be intercepted using a deep extraction well and shallow wellpoints constructed at the edge of the bog. The extraction systems are designed to intercept the contamination prior to reaching the developed bogs. Groundwater modeling was the primary tool to evaluate the different scenarios and select the configuration for the pilot test. The model was refined from the FS-1 Feasibility Study by adding finer discretations to account for the silt and peat layers identified from the previous investigations. The deep extraction was designed to intercept and cutoff the contamination to prevent the contamination from entering the K1 bog. This deep extraction is coupled with shallow re-injection up-gradient of the

K1 bog to maintain and balance the hydraulic system. Deep extraction was modeled at two different screen depths to evaluate the overall performance. Shallow extraction was then modeled with the optimal deep extraction scenario to intercept the contamination before entering the bog system. Two shallow extraction depths were modeled. The first was just below the water table and the second was thirty feet into the water table.

3.1.1 Deep Groundwater Extraction (EW-5)

The location of Extraction Well 5 was adjusted to be near the center of the K1 bog prior to beginning the modeling. The location of the proposed well relative to the EDB plume and K1 bog is depicted on Figure 3-1. The figure also illustrates the other wells used in the FS-1 Draft Feasibility Study (HAZWRAP 1998).

Two different well screen settings were modeled. The first was from a depth of -40 to -100 msl and the second was from a depth of -90 to -150msl. The latter depth was based upon the drilling and sampling at the monitoring well 36MW1003A location. The sampling suggested high purge rates beginning near a depth 120 to 180 feet below the ground surface. The location of EW-5 was also adjusted for accessibility by the drilling equipment and associated equipment.

A plume shell was created to evaluate the different alternatives. The plume shell was created using the data collected from the remedial investigation. The shell was then krieged to a 3-dimensional isoconcentration map (Figure 3-2). This shell formulated the basis of the 250 particles that are seeded in the model for the evaluation. Figures 3-3 to 3-6 presents a planview and cross-section of the seeded particles for the deep groundwater extraction scenarios (No Action, 200, 400 and 600gpm at a screen interval of -40 to -100 msl, and 200 and 400 gpm at a screen interval of -90 to -150msl). Table 3.1 summarizes the model runs and the particles captured by the well or making it to the surface.

The modeling determined that the optimal deep water extraction was from the interval of -90 to -150 feet MSL at a rate of 200 gpm. All of this flow will be re-injected by shallow trench re-injection following treatment. The extraction well is an 8-inches in diameter with a 60-foot well screen. Treated water will be re-injected just above the K1 bog.

3.1.2 Shallow Groundwater Extraction

Two concepts for shallow groundwater extraction were considered. The first was to install an interceptor pipe with sumps along the length of the upwelling in the K2 and K6 bogs. The second was to intercept the shallow groundwater using well points similar to the method being utilized on the Coonamessett River. The location of the interceptor pipe or shallow well points was based upon the modeling information and the results of the drive point sampling. This information indicated that the length would need to approximately 1200 feet in length and have three spokes or legs beginning at the southeastern corner of the K2 bog and in the northeast corner of the K6 bog (Figure 3-7).

3.2 TREATMENT

Extracted groundwater will be conveyed in a single wall pipeline from EW-5 and the vacuum extraction points to a building containing two 20,000-pound GAC vessels. A process instrumental diagram is presented in Figure 3-8. The units will be operated in series with a lead and lag vessel. Samples will be collected from between the vessels according to the monitoring plan presented in Section 6. The water will be treated using pH stabilized granular-activated carbon to remove EDB to concentrations below the reporting limits, if technically feasible. The reporting limit for EDB is 0.01 µg/L. (Detection limits are lower than reporting limits. When data are reported at concentrations between the reporting limit yet above the detection limit, the values are "J" flagged to indicate that the results are estimated.)

The resident time in the GAC will be 4 to 8 minutes. The system will operate continuously, extracting, treating, and discharging approximately 600 to 750 gpm. Because the system will operate continuously, both the lines and treatment system will need to be winterized. For this reason, it will be necessary to construct the units on a concrete foundation and house the canisters in either a metal or wooden building. The building will have a 25 x 40 foot footprint. The footprint of the building is provided on Figure 3-7.

In the event that backwashing is needed, it will be accomplished by pumping treated groundwater into a temporary tank situated near the carbon units. The treated water will then be pulled out of the temporary tanks using a high volume backwash pump. The backwash water would then be directed to the second temporary tank. The supertant, following the backwash, would then be treated through the system after the residing in the tank for several days. Alternatively, the backwash water will be sampled and removed from the site in accordance with the MMR Investigative Derived Material (IDM) Plan. Backwashing or back flushing would only be required if the differential pressure in the vessels exceeded 15 psi.

Extracted and treated water will be contained in single walled HDPE pipe. The minimum burial depth of pipe is three feet. Sodium hypochloride may be added to kill any bacteria prior to entering the GAC. No residual chlorine should remain in the system before it is discharged. Chlorine will not be added unless severe bacterial fouling occurs. Influent and effluent samples will be routinely monitored for iron-reducing bacteria.

The extraction, treatment, and dispersal system would be manually operated but equipped with automatic shutdown in the event of a power outage, a loss of pressure, or high differential pressure. An alarm would signal operators at the SD-5 treatment plant building. The plant will be checked every day as described in Section 5.

3.3 DISCHARGE

Treated water will be discharge to the adjacent surface water bodies and re-injected into the shallow aquifer during the pilot test. The discharge will include provisions to add an eductor near the plant to add ambient air to increase the dissolved oxygen of the treated water. At the FS-28 treatment site on the Coonamessett River, the discharge experienced low dissolved oxygen (less than 3.0 mg/L). The low dissolved oxygen levels were improved by adding a bubbler, Figure 3-9, that provides a water fall or cascading effect to increase the oxygen level at the point of entry into the river system. This effect has increased the DO level to greater than 8 mg/L. Two methods of discharging the treatment water are planned for the pilot test. The eductor is designed to draw ambient air into the pipeline at a rate of 300 standard cubic feet per minute. The air will be taken from within the treatment plant building where the temperature is naturally maintained to 50 to 70°F during the summer and winter.

3.3.1 Surface Water Discharge

The first method will be to discharge treated water to the adjacent surface water bodies just south of the K1 bog and below sampling station 36SW0010. Provisions will also be added such that discharge of treated water can be placed into the swale between the bog access road and the separation berm. Treated water will be conveyed to the bogs using a HDPE pipe from the treatment plant building. Approximately 400 gpm per minute will be discharge to the surface water body. The remainder of the treated water will be re-injected to the shallow groundwater. Discharge points are shown on Figure 3-7.

3.3.2 Shallow Re-injection

Treated water will be re-injected along the north side of the K1 bog. The purpose of the re-injection is to mound the water table on the north side of the bog and allow the treated water to come into the bog rather than contaminated groundwater. The water will be leached back into the aquifer using a shallow perforated pipe. The pipe will be a 4 inch diameter slotted pipe to drain the flow over an area of approximately 500

feet. The pipe will be constructed just below the water table and backfill with clean coarse aggregate (Figure 3-10). Geotextile material will then be placed on top of the drainage aggregate to separate the backfill.

3.4 SEPARATION BERMS AND WATER CONTROL STRUCTURES

Separation berms will be constructed of earthen materials along the perimeter of the K2 and K6 bogs. The purpose of the berms is to separate the area being remediated from the active bogs such that contaminated surface water will not flow into the developed bogs. The berms are an integral part of the pilot test since they provide separation in the event that a power outage occurs and the shallow well point system and treatment is disconnected.

The berms will be constructed with native sandy loam soils. They will have a top width of 10 to 12 feet and sideslopes no steeper than 2 (horizontal): 1 (vertical). Along the Quashnet River, the sideslope adjacent to the river will have a 3 (horizontal): 1 (vertical) slope and be vegetated with native grasses to promote a riparian habitat near the river course. The top of the berm will be covered with aggregate to facilitate a durable surface for access.

Due to the thickness of the peat deposits, a geosysnethic material must be placed where the bog soils and vegetation are stripped. The geosysnethic will be a covered a coarse aggregate near the center. A second geotextile of low permeability will cover this material and then fold over the aggregate materials to produce a reinforced blanket.

Water control structures will also be added to drain the bogs and the perimeter swales. The structures will be constructed of galvanized metal or aluminum and fitted with flumes to control the height of the water.

4.0 PILOT TEST INSTALLATION AND STARTUP

The purpose of this section is to describe the pilot test installation procedures and the startup procedures for the treatment system and well field. Items provided in this section include the site preparation, drilling and well installation procedures, mechanical and piping, electrical and instrumentation installation.

4.1 SITE PREPARATION

Site grading will be required prior to constructing the treatment plant building and the pump house. The existing gravel roadways will be upgraded and improved to a width of 15 feet for truck access during construction and operation of the system. Prior to beginning any grading, erosion control measures such as silt fences or straw bales will be staked 3 feet beyond the toe of any proposed fills and along the edge of the K1, K2, and K6 bogs. The silt fences will be maintained during the course of the construction activities to ensure that no sediment enters the wetlands from the work areas.

Once the silt fences are installed, the area will be cleared and grubbed a maximum of 15 feet beyond the top of a cutslope and 5 feet beyond the fill slope. The topsoil will be stripped, if appropriate, and stockpiled for later re-use on the slopes. The stockpile area will be at least 100 feet outside from the wetlands.

The treatment plant area will be graded to provide a 75 by 100-foot working platform. The area outside of the building footprint will be covered with at least 6 inches of compacted dense graded aggregate. The aggregate will provide a suitable working surface for heavy equipment and serve to stabilize the subgrade. Prior to placing the aggregate, the upper 12 inches of the subgrade will be scarified and re-compacted to 92 percent of modified proctor (ASTM D 1557). The area around the pump house (15 by 20 feet) will be treated in a similar manner for access.

The interior bog berms constructed on K2 and K6 will be 10 to 12 feet wide at the top and sloped on a 2:1 and 3:1 side slopes near the river. The berms will be constructed

of native sandy loam taken from an onsite borrow source located south of the K6 bog. A geotechnical investigation is currently being planned to collect samples of the proposed borrow area. The soils used in the used in the berms construction should have permeability less than 10^{-3} cm/sec when compacted to 92% of modified proctor. In addition, a geosnythetic geogrid material and coarse aggregate may be required to construct the berms over the K6 peat material.

The berms are brought to the finished grade then the sideslopes will be covered with suitable topsoil and re-vegetated with native grasses. The topsoil may be derived from soils stripped prior to placing the berms. The materials should not be erodable and have sufficient organic matter to support a native grass material. Erosion netting may also be required on the sideslopes. The top of the berms shall be crowned and covered with a minimum of 6 inches of dense graded aggregate.

4.2 DRILLING AND WELL INSTALLATION

One deep groundwater extraction well will be drilled to intercept the contaminated groundwater prior to upwelling into the bogs. The extraction well will be drilled to a total depth of 185 feet below such that a 60 foot well screen can be installed. The well should be capable of producing 200 to 600 gpm. The slot size of the well screen will be designed after the borehole is drilled. The well casing will be 8-inches in diameter and constructed of schedule 40 carbon steel. The casing joints will be welded. The well will be developed in accordance with MMR Tech Procedure 046.

A submersible pump with a downcomber pipe will be installed in the completed well. The pump setting will be located near the top of the screen interval with a downcomber pipe installed beneath the lowest silt unit. The 25 hp pump will have a total dynamic head of 150 feet. The well will be installed inside a concrete vault with a man-way hatch. The vault will be at least 6 inches above the ground surface and graded to prevent any surface water run-on. A manual gate valve, check valve, and pressure gauge will be installed in the vault. The well will be started and stopped from the treatment building.

The shallow wellpoints will be installed as indicated on Figure 3-7 at a spacing of approximately 10 feet. The wellpoints will be located just off the edge of the existing bog road and placed in the channel. Sediments will be trapped at the toe of the slope using a silt fence or hay bales. The header pipe will be sloped from the pump house with a grade not less than 0.2% such that the pipe will drain back into the well points if the vacuum is lost due to a power outage.

4.3 MECHANICAL AND PIPING

The primary components of the mechanical and piping systems that will be used at the Quashnet pilot plant are described in the following paragraphs.

4.3.1 Extraction Well, Well Point Extraction System and Piping

The extraction well will be constructed of 304 stainless steel screen and carbon steel casing. A stainless steel submersible pump will be installed in the well with discharge pipe up to a concrete well vault. The discharge piping will have threaded connections up to the well vault where it will transition at a flanged connection to the HDPE pipe that extends to the treatment building. Single wall (6-inch) diameter HDPE pipe will convey the extracted water to the treatment plant building.

The wellpoints will be constructed of carbon steel. Vacuum header piping will be carbon steel up to the pump house building. A case iron pump will provide the vacuum to the well point system and direct the discharge to the treatment plant. Discharge from the pump house to the treatment plant will be provided using 6 –inch single wall HDPE pipe. The vacuum pump will communicate with the treatment plant for shutdown.

The operator will check the flow meters that indicate the flow rate into the treatment system. If the flow rates have dropped significantly, the operator will know that a major failure has occurred and can shut off the flow from the wells. The wellfield will shutdown if the line pressures exceed 125 psi.

4.3.2 Activated Carbon Units

Experience from treating EDB from the FS-28 plume has shown effective removal to below detection limits with an design empty bed contact time of 8 minutes. Two 20,000-pound carbon beds in series will be used, which is the largest standard size unit. The 20,000-pound size is based on the capacity of the trucks used to deliver the carbon. At the design flow rate for the treatment plant of 600 gpm, these carbon beds will provide a 8 empty bed contact time. The vessels will be loaded with pH stabilized virgin carbon.

The system is designed so that there will be two carbon beds in series. It is estimated that a carbon bed will need to be changeout about once every 6 months. Whenever a bed is removed from service for regeneration, the extraction systems will be temporarily shut down for the at least one day to replace the carbon. A change out will occur when the EDB concentrations in the intermediate sampling port (between the lead and lag) exceed the state maximum contaminant level of 0.02 μg/L. If a EDB is detected but below this threshold an additional sample will be taken from the effluent to ensure that the effluent is non-detect. No pretreatment is presently being considered since the influent iron concentrations are less than 1 mg/L.

Space is provided to bring in trucks to remove the spent carbon and to bring in fresh carbon. The truck spot is located outside of the building, on the gravel pad. Virgin carbon will be transported wet and slurried into the vessels according to the manufacture recommendations.

4.3.3 Backwash System

The backwash system will consist of a centrifugal cast iron pump plumbed to the carbon adsorber manifold system. Treated water is stored in one of the frac tanks located outside the building. Backwash will be initiated by the operator based on excessive differential pressure across a carbon unit (for example 15 psi). The backwash pump is connected to the frac tanks by carbon steel piping and flexible

hose. Gate valves isolate the tanks and the pump for maintenance. The backwash pump directs treated water from the frac tank up through one of the carbon units at a velocity sufficient to fluidize the carbon. The system may also be backflushed at a lower flowrate so the bed is not expanded. During backwashing, particulate material is release by the carbon and carried with the backwash water to the other frac tank. After sufficient settling period, the water will be decanted and treated at the plant.

4.3.4 Piping and Valves

All interior piping will be welded carbon steel with flange connections at valves, flow meters, and other in-line equipment. All valves will also be carbon steel. Pipe hangers and supports will be galvanized carbon steel. All piping will be sloped to allow for complete drainage of the system and labeled based on service. Exterior, above-grade piping will be insulated and heat traced to prevent freezing.

4.3.5 Discharge/Reinjection System

No disinfection of the treated water will be required for discharge or reinjection. However, a spool piece will be left such that a eductor can be added to the system to improve the oxygen content.

The design basis location, screen lengths, and flow rates for the reinjection trenches are based on 200gpm with a 20% safety factor added to the flow rates. However, the flow rate into any individual trench is limited only by potential plugging in the sand and gravel pack around the perforated pipe and the head pressure exerted by the pumps.

However, some degree of plugging may occur in the reinjection trench, so the following provisions have been made to offset the plugging impact:

- The pumps have been designed to provide a minimum of 10 psig pressure at the trench in case pressure is required to force the water into the groundwater formation.

- Cleanouts will be added at either end of the reinjection pipe such that the line can be periodically cleaned to remove any buildup. Room for hypochlorite injection facilities has been provided at the treatment system in case continuous or periodic addition of chlorine to reduce biological activity becomes necessary at the influent or discharge locations.

In addition to the above provisions provided to minimize the plugging impact, additional provisions have been made to provide flexibility into the reinjection system:

- The reinjection well header is designed to operate at low flows allowing for future expansion in flow rates.
- Control valves have been provided which utilize 20% of the system pressure drop. If the control valves are allowed to operate wide open, the flow rate to all the wells can be increased by 25%.
- Isolation valves have been provided in the reinjection trench header, plus blind flanges have been provided at strategic points on the header, to allow the future installation of additional trenches or wells without taking the entire header out of service.

4.4 ELECTRICAL AND INSTRUMENTATION

The pilot plant system will be supplied electrical power from a new service line brought to the site from Hooppole Road and Grafton Pocknet Road by Com Electric. The service will be 480 V, 3-phase power at the pilot plant to run the pumps. Transformers will step the power down to 120/240-volt, single-phase lighting and small power load panel at the treatment plant. Panel boards and motor control centers will be mounted to the walls inside the plant. A programmable logic control will be used to automatically operate and control the plant. No standby generator for backup power will be provided since short-term shut downs are not expected to effect the groundwater capture.

The pilot plant system will be designed to normally operate unmanned. The control signals will be sent to the SD-5 North treatment building, where operators will

normally be on duty. The extraction well, the well point system, and the treatment system will be on automatic control.

If an upset condition occurs, alarms will warn the operators at the SD-5 North treatment facility that action is required at the Quashnet pilot plant. Most of the upset conditions will require that the operators drive to the pilot plant.

The components of the control systems are shown on Figure 3-8, the process and instrumentation diagram. The following is a summary of the major control features:

- The pumping rates from the extraction well and the well point extraction system are on flow control. This is one of the most important control variables. Monitoring wells will be used to measure the groundwater levels and the concentrations of contaminants in the plume to insure that the extraction rates are meeting the plume containment goals. The flow rate from each system will be adjusted to achieve the containment goals.
- Operation of the carbon filters is on manual control. High differential pressure alarms will warn the operator if a carbon bed is being plugged. The system will automatically shutdown if the differential pressure exceeds 15 psi. Samples will be collected and analyzed from between the first and second bed to monitor when the carbon in the first bed is becoming exhausted. When toxic organic compounds are detected in the outlet from the first bed above the cleanup levels, the carbon in that bed will be replaced and the order of the beds will be swapped. The bed with the fresh carbon will move to the second position. During the period when the carbon is being replaced, the extraction will be shut down.
- The flow rate to each part of the discharge/reinjection system is on flow control. The pressure in the discharge/reinjection system is monitored in addition to the flow of the water. The level and pressure both provide an indication of any fouling that will restrict flow. The flow rate will be adjusted periodically based on feedback from the levels in the monitoring wells, to insure that the reinjection aids the goal of capturing the plume without significantly impacting the groundwater levels in the area.

The following controls are provided for the extraction well and the well point extraction system:

- The flow rate is automatically controlled by flow control valves. This flow will be adjusted, based on information obtained from the monitoring wells to insure that the plume containment goals are being achieved.

- The water level in the extraction well is indicated in the control room to allow the operator to monitor the level in the plume and/or as an indication of plugging of the well screens.
- A low-level cutoff is provided in the extraction well to protect the pumps against excessive drawdown.

4.5 STARTUP PROCEDURES

Startup of the treatment system will be performed in two steps. Upon completion of the installation, Jacobs and its subcontractors, in conjunction with appropriate AFCEE and base personnel, will check out the electrical, mechanical, and hydraulic elements of the treatment facility. The system will be started using clean water brought to the facility from the ANG Base. The system will then begin using actual groundwater withdrawn through the extraction wells. Startup of the extraction/reinjection wells will be a phased operation. The extraction/reinjection wells will be operated at less than the design flow rates for several weeks to assess groundwater capture and hydrologic environmental impacts prior to full-scale operation.

When the plant is mechanically complete, commissioning and start-up procedures will be followed.

5.0 PILOT PLANT OPERATION AND MAINTENANCE PROCEDURES

This section presents the operation and maintenance procedures for the Quashnet Pilot Plant System. It includes sections on personnel duties and responsibilities, records and reporting requirements, maintenance requirements, emergency response procedures, safety, and utilities.

5.1 PERSONNEL DUTIES AND RESPONSIBILITIES

Operation and maintenance of the pilot test system will be the responsibility of Jacob's Field Services Operation and Maintenance personnel. A plant superintendent, treatment plant operator, and maintenance technician will be identified for the pilot plant. The duties and responsibilities of these personnel are described in the following subsections.

5.1.1 Plant Superintendent

Overall management and leadership will be provided by the plant superintendent. The superintendent has overall responsibility for the safe, efficient, and economical running of the pilot test treatment system. The superintendent will normally work eight hours a day, Monday through Friday, and will be subject to call-out 24 hours a day, seven days a week. The plant superintendent's specific duties include:

- Implementing and running the on-site safety program, including obtaining permits for welding, confined space entry, and ensuring that a safe plan of action is developed and that proper personal protective equipment (PPE) is worn by all personnel in the plant.
- Ensuring that all personnel assigned to the project follow quality procedures.
- Insuring that system checks, routine and preventative maintenance are carried out, and logs and records are maintained.
- Administering personnel functions, including the record keeping, hiring, evaluating, and training of personnel.
- Initiating actions to improve the preventative maintenance systems.
- Insuring that adequate repair parts, consumables, and supplies are on hand.
- Insuring that all reports are completed and distributed as required.

- Supervising repairs.
- Preparing operation and maintenance budget.
- Acting as a liaison with base personnel.
- Developing improvements to save costs and to insure the effectiveness of the system.

5.1.2 Treatment Plant Operator

There will be a qualified wastewater treatment plant operators assigned to the treatment system. The operator will have the appropriate Commonwealth of Massachusetts Certification or will be under the direct supervision of someone who has the certification. The operator will have the necessary experience and necessary technical skills to carry out the duties listed below:

- Follow all safety procedures;
- Follow all quality control procedures;
- Provide daily operation and maintenance of the treatment systems equipment and control systems;
- Conduct visual checks and inspection of equipment and the control system to ensure that all systems are operating normally;
- Make adjustments as necessary;
- Take records and interpret readings;
- Unload stocks and load waste;
- Conduct routine and preventative maintenance and make repairs;
- Take samples and perform in-house analyses (YSI, Hach kit) or send samples to an offsite laboratory for analysis;
- Based on results, make adjustments to the system or consult on required adjustments;
- Complete and distribute reports;
- Inspect and maintain grounds and facilities;
- Ensure that the treated water meets clean-up levels; and
- Submit discharge monitoring report to regulatory agencies.

5.1.4 Maintenance Technicians

There will be two maintenance technicians available as needed: one with mechanical skills (pipefitting, welding, millwright) and one with electrical and instrumentation skills. Their specific duties and responsibilities will include:

- Follow all safety procedures;
- Follow all quality control procedures;
- Plan and evaluate preventative maintenance of waste water treatment facilities and equipment;
- Perform maintenance and repair work on the equipment;
- Lubricate equipment and check for malfunctions;
- Replace packing in pumps or valves; replace bearings in motors, pumps, and other equipment; clean out pipes and perform other plumbing and pipe-fitting tasks as required;
- Inspect and service the mechanical systems, electrical control systems, MCC, and instrumentation;
- Maintain repair and general maintenance logs and records;
- Initiate orders for parts;
- Maintain adequate inventories of parts; enforce safety regulations; consult with equipment vendors;
- Supervise, instruct, and inspect the repair work of contractors; and
- Investigate new or alternative materials, parts, tools, and procedures to increase the life and efficiency of process equipment.

Train personnel in the proper procedures in servicing and repairing the facilities and related equipment of waste water treatment plants and pumping stations.

5.2 RECORDS AND REPORTING

The pilot plant operation and monitoring program will be documented through logs, records and periodic reports described in the following paragraphs. A document distribution list will be developed. Records will be maintained in a dry, secure area

of the at the SD-5 North treatment plant and disposal will be in accordance with U.S. Air Force regulations.

5.2.1 Daily Activity and Operation Logs

An activities log will be kept at the treatment system control building in a bound logbook. The log will describe all daily activities associated with the groundwater treatment systems. The log will provide sufficient data to reconstruct events occurring at the treatment system. All entries will be dated. At minimum, the log will contain the following components:

- a summary of all daily activities associated with the treatment system, including equipment inspections and maintenance activities;
- a summary of observations of all unusual equipment operation;
- a list of persons who visited the site; and
- a list of sampling activities.

A daily operating log similar to Table 5-1 will be kept for in-plant use. Plant operators will take readings daily and record results on the log sheet. The log will be kept for the permanent file and retained for a minimum of ten years.

5.2.2 Process Equipment O&M Logs

This log is used to record pertinent information such as flow rates and totals, lead and lag vessels, differential and total pressures and outlet pressure (Table 5-1).

A separate record for each piece of installed equipment will be maintained for the life of the facility. These records will be maintained on a record card (Appendix D). These cards will be updated when any work is performed. At a minimum, the equipment listed in the equipment register (Appendix D) will have a separate card. Instruments may be grouped by type and manufacturer.

5.2.3 Field Sampling Log

This log is used to record pertinent analytical results. This will include information on VOCs, SVOCs, EDB, total iron, manganese, TSS, TDS, TOC, H_2O_2, pH, temperature, turbidity, oxygen reduction potential (ORP), specific conductance, and chlorine (Table 5-2). This log provides performance data which verifies treatment process.

5.2.4 Progress Reports

Various reports will be generated to present a complete update of system operation. These reports will supply information necessary to ensure optimum system operation. This update will also create an evaluation and feedback process between field and engineering personnel. The following items will be included in the reports:

- O&M summaries,
- action items/status,
- work planned for the next quarter,
- results of performance audits,
- quality assurance (QA) problems encountered and corrective action taken,
- summary of DQOs and validation,
- Daily Summary Report.

A section of the Monthly Progress Report will present available O&M data and summarize the treatment system O&M and performance issues. The following general types of information will be included:

- treatment system and facility condition,
- operational data,
- water-level elevations for the extraction and monitoring wells,
- data interpretation,
- equipment problems and recommended solutions,

- general recommendations,
- work planned for the next month.

5.3 MAINTENANCE

This section provides a separate maintenance program for the routine inspection, cleaning, preservation, lubrication, adjustment and minor repair of the pilot treatment system. Routine and periodic maintenance increases plant reliability, reduces costly repairs, reduces the possibility of an accidental release of hazardous materials and increases plant efficiency. Therefore, plant operators and maintenance technicians will become familiar with this section and will be trained in routine maintenance practices.

There are four general areas that require maintenance:

- Buildings and grounds
- Wells
- Pipelines
- Equipment.

5.3.1 Routine Maintenance

The following systems will be inspected daily for proper operation, leaks, unusual vibration, unusual noise, etc., and corrective action initiated to repair and discrepancy noted:

- carbon filter system
- pumps
- electrical
- instrumentation/control system.

All exposed pipelines and inline valves, specialty items and instruments will be inspected daily for leaks. Major leaks will be repaired immediately by either isolating

the leaking section of pipe or by shutting down the system. Minor leaks will be repaired as soon as possible.

The pilot plant building will be kept neat and clean at all times. Other maintenance will consist of painting and preservation of metal surfaces, minor repairs to damaged surfaces, and lubrication of moving parts, e.g., hinges, door rollers. The grounds surrounding the buildings, parking area, and truck unloading areas will be policed daily, and routine mowing, trimming and fertilizing of landscaped areas will be performed as necessary.

These checks will be performed and recorded daily on the check-off sheet in Appendix D.

5.3.2 Periodic and Annual Maintenance

The following systems will be periodically maintained or inspected for proper operation, leaks, unusual vibration, unusual noise, etc., and corrective action initiated to repair and discrepancy noted:

- Extraction well and well point extraction system
- Pipelines
- Rotating machinery
- Reinjection and discharge systems

An annual inspection of extraction wells, and pumps will be conducted to insure the integrity of the piping, valves and instrumentation. Confined space entry procedures are to be followed when conducting inspections. Whenever a component is worked on, lock out/tag out procedures will be followed.

Extraction and reinjection pipelines will be patrolled daily. The inspection ports, vault, and isolation vaults will be inspected annually, and the condition noted and

corrected where possible, with work orders initiated to correct anything requiring special service.

5.3.3 Emergency Maintenance

Leaks, equipment failures, and other maintenance problems encountered during daily inspections or indicated by the pilot plant alarm system will be addressed immediately to minimize the down time of the pilot plant. If necessary temporary repairs may be made to keep the plant operational until permanent repairs can be completed. At no time, however, will emergency maintenance be performed that will result in unsafe conditions.

5.3.4 Spare Parts Inventory

Parts lists from each manufacturer will be received and included in the Vendor Data Book that will be prepared for the treatment plant. For the start-up and initial operation, each vendor will be contacted and requested to identify the spares needed for start-up and three months of operation. A detailed list of the initial stock will be maintained, and the stock managed by the chief operator. Based on usage and restocking times, additional spares will be ordered.

Major consumable supplies consist primarily of lubricants. Other supplies consist of janitorial items. The existing stock of tools, equipment and safety equipment maintained at the SD-5 treatment plant will be used for maintenance work. This stock of tools generally consists of:

- electrical test meters
- electrical tools
- mechanic tools
- safety supplies
- safety meters/test equipment

All of the above will be controlled as necessary to maintain accountability.

5.3.5 Troubleshooting

Detailed troubleshooting guides for each installed item will be provided by each manufacturer. These guides will be assembled into a Vendor Data Book for the treatment system. At a minimum, troubleshooting guides for will be available for:

- extraction wells
- influent system
- backwash system
- activated carbon
- reinjection system

5.6 EMERGENCY OPERATING AND RESPONSE PROGRAM

These sections describe procedures for performing emergency planning, providing emergency equipment and supplies, handling emergency medical treatment, providing for fire protection, and other equipment failure. A task-specific safe plan of action (SPA) will be developed and will include emergency prevention and recognition of specific tasks. The Program Health and Safety Manager, in coordination with the Treatment Plant Operator, performs the applicable emergency planning tasks before starting field activities, and coordinates emergency response with the facility personnel and local emergency service providers, as appropriate. Jacobs' Corporate Health and Safety Procedure (CHSP) 7.3.7 (Jacobs 1997) provides guidelines for emergency planning and response.

5.6.1 Emergency Communication

Radios and portable phones will be used for emergency communications. When using radios, personnel will contact the Jacobs base to obtain emergency assistance. When calling for an emergency response by telephone or radio, the following information should be reported:

- name and association;
- location;
- type of emergency;
- time of incident; and
- type of first aid or response required.

The caller should not hang up until the emergency responder has released the caller.

5.6.2 Response Measures

Response measures will be implemented based on the nature of the emergency. First aid equipment will be available at the pilot plant. Other response equipment will be available at the SD-5 North Treatment facility which can be rapidly mobilized to the pilot plant.

5.6.3 Spill Control

In the event of a spill or release, notify the Treatment Plant Operator and Health and Safety Officer immediately. They will be responsible for ensuring that necessary notifications are given to the Program Health and Safety Manager and the client. The client and Jacobs will determine the strategy for notifying regulatory agencies. Follow CHSP 11.7, Spill Containment (Jacobs 1997) for disposal and decontamination procedures for all chemicals listed.

5.6.4 Equipment Failure

In the event of equipment failure, take emergency action to shut down the equipment and isolate it if possible. Immediately notify the plant superintendent and program health and safety manager. Evacuate personnel as necessary.

5.6.5 Power Outages

Power outages at the treatment plant will trigger an emergency shutdown. Detailed shut down procedures including emergency shutdown procedures are included in Appendix D.

5.7 SAFETY

A Safe Plan of Action (SPA) is to be prepared before any work task is performed according to Jacobs CHSP 2.1. This information provides a starting point only. Additional hazards that may be encountered will be identified and noted prior to a task being started. Also the following SOPs related to safety will be followed:

- Emergency Planning and Response, SOP 7.3.7
- Fire Prevention, SOP 20.1
- Fire Extinguishers, SOP 20.3
- General Fire Protection, SOP 20.2
- Confined Space Entry, SOP 7.2
- Excavations, SOP 8.4
- Lock Out/Tag Out, SOP 15.1
- Flange Breaking, SOP 8.5
- Safe Plan of Action, SOP 2.1
- Spill Containment, SOP 11.7
- Emergency Evacuation Procedure, SOP 14.1
- Accidents, Injuries, and Illnesses, SOP 5.1
- Vehicle Accidents, SOP 5.2
- Accident Summary of Statistics, SOP 5.3

5.7.1 Site Controls and Security

The appropriate site security (e.g., warning signs, site access procedures, 24-hour patrol during construction) will be provided. Site control and security are meant to prevent the spread of contamination and to control the flow of personnel, vehicles,

5.7.1 Site Controls and Security

The appropriate site security (e.g., warning signs, site access procedures, 24-hour patrol during construction) will be provided. Site control and security are meant to prevent the spread of contamination and to control the flow of personnel, vehicles, and materials into and out of the work areas. Procedures for the implementation and enforcement of safety and health rules for all persons on the site will be established. These procedures apply to employers, employees, outside contractors, government representatives, and visitors.

A visitor's log of anyone visiting or working on the site will be maintained at the site during construction. The visitor's log will include the following: date, name, agency or company affiliation, time entering and exiting site, and PPE used. Before visitors are allowed to enter the controlled area, they will be required to show proof of current training, medical surveillance, and, if respirators are required, respirator-fit testing.

Security signs will be printed in English in large bold letters on contrasting backgrounds. Security signs will be visible from all points of entry.

Very little fuel will be available in the buildings to sustain a fire; however, in accordance with the Massachusetts Building Code, the following will be provided for fire protection:

- access doors for escape from the treatment buildings,
- fire and smoke detectors,
- fire extinguishers,

5.7.2 Hazard Evaluation

A hazard evaluation for the pilot plant system has been performed and the hazards identified are described by type in the following paragraphs.

5.7.3.1 Chemical Hazards

The chemical substance expected to be present at the site other than small quantities of lubricants is granular activated carbon. Wet activated carbon removes oxygen from the air. The limit of activated carbon's capacity for oxygen is not known. However, it should be assumed that all carbon will exhibit this characteristic. A confined space entry procedure must be established for any facility using carbon in confined vessels. Low oxygen levels exist in restricted areas containing wet activated carbon.

All confined spaces, including those containing activated carbon, should be presumed to be hazardous. Appropriate safety measures must always be taken before entering, as well as when workers are in a confined space. Strict adherence to regulations applicable to respiratory protection in an oxygen-deficient atmosphere (<19.6%) shall be followed.

5.7.3.2 Operational Hazards

General plant risks include potential exposure to both physical and chemical hazards. Physical hazards include primary noise, slips, trips, falls, overhead bump hazards and rotating machinery. The pressurized vessels and pipelines in the plant present potential hazards.

5.7.3.3 Maintenance Hazards

Well and Pump Maintenance. The extraction well is enclosed in a concrete vaults that is approximately 8 feet long, 4 feet wide and 4 feet deep. Access will require personnel to follow Jacobs CHSP 7.2, Confined Space Entry. Maintenance activities will require the use of CHSP 15.1, Lock-Out/Tag-Out procedures and possibly CHSP 8.5, Flange Breaking. If workers will be introducing air-borne contaminants into the vault during maintenance, air moving equipment or respiratory protection may be needed. Consult the PHSM prior to entry under these circumstances.

Pipeline Maintenance. All of the HDPE extraction and re-injection pipelines are greater than 3 feet below grade. Refer to CHSP 8.4 for procedures on excavation safety (Jacobs 1997). All soils in this area have been classified as type C per OSHA 29 CFR 1926.652. The soil in general is granular and requires shoring or a 1½:1 slope on all excavations over 5 feet deep.

The in-plant pipeline system consists of carbon steel pipe. Any cutting, heating, grinding or welding of galvanized steel or other coated materials requires coordination with the PHSM. Access to pipe racks will require fall protection. Removal of any valves or other pipeline components will require lock-out/tag-out and flange breaking procedures to be followed. See Jacobs CHSP 15.1, Lock-out/Tag-out, and CHSP 8.5, Flange Breaking (Jacobs 1997). All double-walled pipe block valves in the header to the influent tank will be car-sealed open during normal operations to provide over-pressure protection.

Vessel Maintenance and Inspection. All vessels in the treatment plant are classified as permit-required confined spaces. Any entry into these vessels requires a confined space entry permit issued by PHSM (CHSP 7.2, Confined Space Entry).

Chemical and Contaminated Materials Transfer. Prior to transferring chemicals or contaminated materials, the proper personal protective equipment (PPE) must be worn. The OSHA-defined levels for protection are defined in attachment 4 to Jacobs Corporate Health and Safety Plan (CHSP) 13.2 and Appendix B to 29 CFR 1919.120. Contaminated granular-activated charcoal will be removed from the Calgon tanks as a slurry. Workers must wear Tyvek, gloves, and chemical goggles. There is a potential for organic vapors to be present during the transfer. Air monitoring with a photoionization detector (PID) must be conducted throughout the transfer. If results exceed 5.0 ppm, workers must upgrade to level C and continue air monitoring. If air levels exceed 100 ppm, operations shall be terminated, and the PHSM notified.

5.7.3.4 Biological Hazards

Biological hazards at the site include disease vectors such as deer and wood ticks, and vermin (e.g., skunks, raccoons). Various poisonous spiders may also be encountered. Poison ivy and poison oak are indigenous. Preventive measures, such as harborage control and general housekeeping, should be taken to minimize exposures when working outdoors. Trash should be disposed of in closed containers in order to minimize small animal intrusion.

5.7.4 Hazard Communication

Hazard communication training will be completed for pilot plant operation and maintenance personnel. Employee hazard communication (HAZCOM) training will include at least:

- Methods and observations that can be used to detect the presence or release of a hazardous chemical in the work area (such as the kind of monitoring conducted by O&M personnel, continuous monitoring devices, and visual appearance or odor of hazardous chemicals).
- The physical and health hazards of the chemicals in the work area.
- The measures employees can take to protect themselves from these hazards, including specific procedures implemented to protect employees from exposure to hazardous chemicals, such as appropriate work practices, emergency procedures, and proper PPE.
- The hazard communication program includes an explanation of the labeling system, the Material Safety Data Sheet, and how employees can obtain and use the appropriate hazard information.

5.7.5 Safety Training Requirements

Personnel will receive training in accordance with Federal Occupational Safety and Health Administration (OSHA) regulations. Personnel entering controlled areas must have successfully completed 40 hours of hazardous waste instruction offsite, 3 days of actual field experience under the direct supervision of a trained experienced supervisor, and 8 hours of refresher training annually.

Prior to commencement of treatment operations, all site personnel, including visitors and suppliers, who enter the controlled areas will attend a site-specific safety and health training session. This session will be conducted by site safety personnel to ensure that all personnel are familiar with the requirements and responsibilities of maintaining a safe and healthful work environment.

Periodic onsite safety training will be conducted. This training will address safety and health procedures, work practices, any changes in work tasks or schedule, results of the previous week's air monitoring, review of safety discrepancies and accidents, and activity hazard analyses.

5.7.6 Medical Surveillance

All personnel working onsite will be included in the medical surveillance program. Subcontractor personnel working onsite must provide documentation that they have participated in a medical surveillance program that complies with state and local regulations. Documentation of current medical surveillance exams must be maintained.

The medical surveillance program will include scheduling examinations, certification of fitness for duty, compliance with OSHA requirements, and information provided to the physician. The medical surveillance program will keep a record of the frequency of examinations, and the content of examinations.

5.7.7 Personnel Protection Equipment

The Program Health and Safety Manager (PHSM) will establish the appropriate levels of protection for each work activity, based on a review of historical site information, current data, and an evaluation of the potential for exposure (inhalation, dermal, ingestion, and injection) for each task.

The PHSM will also establish action levels for any upgrade or downgrade in levels of PPE. The protocols and communication network for changing the level of protection

address air monitoring results, potential for exposure, changes in site conditions, work phases, job tasks, weather, temperature extremes, and individual medical considerations.

Onsite personnel will be provided the required PPE, which must be kept clean and well maintained. The PPE section of the Site Health and Safety Plan will include site-specific procedures to determine PPE program effectiveness and onsite fit-testing of respirators, and the cleaning, maintenance, inspection, and storage of PPE.

5.8 UTILITIES

The pilot plant will not be equipped with potable water, sewer, or natural gas. The only utility used by the pilot plant will be electricity. A new electrical service will be brought into the pilot plant site from Grafton Pocknet Road. Commonwealth Electric Company will be responsible for maintenance of the service up to and including the transformer located at building site. The electrical maintenance technician will be responsible for all maintenance from the transformer to the pilot plant and equipment within the pilot plant. Electrical usage will be tracked through regular metering readings by Commonwealth Electric Company.

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6.0 MONITORING PLAN

The purpose of this monitoring plan is to outline the environmental sampling for the area surrounding the Quashnet River and proposed Quashnet Pilot test area, and the leading edge of the ethylene dibromide (EDB) plume associated with Fuel Spill-1 (FS-1). The emphasis of this plan is centered on risk management and system performance and impact monitoring for the ongoing and proposed response actions for FS-1. The specific aspects for this environmental monitoring program are (1) environmental monitoring to manage risk to human health from EDB exposure, (2) system performance monitoring, and (3) ecological impact monitoring.

Surface water sampling will be conducted to manage human health risk and assess the marketability of the bogs on the Quashnet River. Surface water in the Quashnet River will be sampled to monitor EDB concentrations for the purpose of managing risk to human health. On a monthly basis, surface water samples will be collected from 36SW0001, 36SW0002, 36SW0201, 36SW0003, 36SW0036, 36SW0010, 36SW0200, 36SW0015, 36SW0220, and 36SW0203 for EDB analysis (see Figure E2-1 of Appendix E). Samples will also be collected monthly from the developed bogs. Furthermore, all of the bogs will be sampled three weeks prior to harvest and at the harvest period. With the exception of the harvest period, all of the analyses will be on normal turnaround times.

Air will be sampled if EDB in surface water concentrations exceeds 0.5 micrograms per liter (μg/L).

Treatment plant performance monitoring will be conducted for the pilot test system. The pilot test system includes one extraction well (36EW005 for the location see Figure E3-1 of Appendix E) screened in the area of the highest levels of EDB and granular-activated carbon treatment. Analytical data will also be collected from nearby monitoring wells (36MW1001A, 36MW1003A, MW131AB, MW132ABC, and MW133, see Figure E2-2 of Appendix E) to evaluate the effectiveness of the extraction well 36EW005 and extraction well points on removing the high

concentrations of EDB in the groundwater. Sampling of the treated groundwater at the surface sampling ports at the north side of Bog K-1 will be conducted to meet the requirements of the Massachusetts Department of Environmental Protection (DEP) and the U.S. Environmental Protection Agency (EPA) regulations for the protection of aquatic life. Baseline groundwater quality at the extraction well 36EW005 site will be evaluated by collecting groundwater samples from the extraction well following development.

The FS-1 and Quashnet Bog ecological monitoring of water levels, and physicochemical, chemical, and biological parameters will be used to assess potential adverse impacts to ecosystems from groundwater extraction and the discharge of treated groundwater to the Quashnet River. This ecological monitoring will be conducted in accordance with the ecological work plan (AFCEE 1998b). The ecological monitoring will be integrated through various aspects of the operation and maintenance program, performance monitoring evaluation program, and risk management objectives. Physicochemical samples will be collected monthly from (1) groundwater wells (36MW1001A, 36MW1003A, MW131A, MW131B, MW132A, MW132B, MW132C, and MW133) (2) surface water location (36SW0010, 36SW0222) upgradient of the 36EW05 extraction well, (3) from the effluent at the point where the treated water is discharged to the river (36SW0300), and (4) from one surface water monitoring location (36SW0003) downstream of the effluent discharge point. Potential adverse impacts to ecosystems will be determined through comparisons of data from pre-treated groundwater, treated groundwater that is discharged to the river, and surface water downstream of the treatment system. Surface water samples will be collected and analyzed for physicochemical and chemical parameters at ecosystems of concern to monitor for potential adverse ecological impacts from the groundwater treatment system. Physicochemical parameters in surface water will be measured six times per year.

The Plant Performance Assessment Team (PPAT) is a multi-disciplinary team that meets bimonthly, or as needed, to assess plant performance and provide direction to

plant operators. This team will develop measurable assessment parameters and dynamic ranges of the groundwater treatment plant effluent to ensure that the discharge water adheres to state and federal regulations. The team will also be tasked with reporting assessment parameter exceedances to EPA and DEP. A technical report will be prepared each quarter. Details of the monitoring plan supported by figures and associated tables are included in Appendix E.

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7.0 DATA ANALYSIS AND INTERPRETATION

The pilot test is being utilized to evaluate effectiveness of the extraction system in intercepting both deep and shallow groundwater, performance of the treatment, and re-injection of treated water back into the aquifer. Data will be collected during the system startup and monthly during the pilot test period of performance. The monitoring plan previously presented will be interpreted and verified to arrive at conclusions on the performance of the system in meeting the objectives of the pilot test. A pump test will be completed during the system startup to provide data on the aquifer. Evaluations will then be presented after 3 months, 6 months, and 1 year of operation of the systems.

7.1 PUMP TEST

A pump test will be performed to evaluate the hydraulic characteristics of the aquifer and determine the extraction well's zone of influence. The objectives of the pump test are as follows:

- To determine the aquifer transmissivity and hydraulic conductivity of the lower part of the aquifer at this location
- To provide data to calculate the vertical-to-horizontal anisotropy ratio for input into the groundwater flow model.
- To measure any impacts to the K1 bog and nearby wetlands during pumping.
- To determine the extraction well zone of capture.

The pump test will be completed during the plant startup and prior to tuning the shallow well extraction system. The target pumping rate of this test will be 500 gallons per minute (gpm). This rate maybe adjusted based on estimated aquifer transmissivity, numerical modeling results, and well development data. The selected pumping rate should be great enough to place a relatively large stress on the aquifer without dewatering more than 20 percent of the saturated outwash thickness by test end.

Drawdowns in wells screened at the same elevation as the pumped well and within 300 feet of the pumped well should reach a minimum of 0.5 feet so that hydraulic influences external to pumping are likely to be minor, and actual drawdown can be accurately determined. To assure that drawdown data of high quality are collected, automated electronic dataloggers with downhole pressure transducers will be used at all key monitoring wells. Additional piezometers may be required to monitor the shallow and deep water levels. A list of those wells to be monitored or installed will be provided at least three weeks in advance of the test.

Groundwater levels will be recorded with data loggers for selected locations for a minimum of two days before the pumping test and one day beyond a recovery period equal to the pumping duration, so as to establish the background trend. Data collected from the pump test will be utilized to re-calibrate the groundwater model. Predicted heads from the model will be matched as closely as possible to the measured heads. The modeling will then be used to determine the radius of influence and the mass capture of the extraction system.

Once the pumping test is completed, the shallow well field will be brought on line and the extraction well pumping rate will be reduced to approximately 200 gpm. However, prior to making this adjustment, a series of step tests will be performed on the shallow well field to determine the optimal pumping rate based upon flow and contaminant reduction. After the two tests are completed, the entire system will be brought into equilibrium to adjust the re-injection of the treated water.

7.2 EVALUATION REPORTS

Evaluation reports and updates will be provided after three months, 6 months and 1 year of continuous operation. The objectives of the evaluations are as follows:

- Determine the zone of capture and the radius of influence for the installed system using modeling and field measurements.
- Discuss the startup results and the influence on the reducing the levels of EDB in the surface water.

- Judge the ecological impacts of the extraction and treatment system based upon the measurements taken during past year.
- Present recommendations for changes to the monitoring plan or system to ensure that the goals are being attained.

The evaluations will be presented to the stakeholders as a technical memorandum. The content of the technical memorandum will also be briefed at a public meeting. Tentative dates for the evaluation reports are as follows:

- System Startup – June 22, 1999
- Semi-Annual Performance Evaluation - September 30, 1999
- One Year Evaluation - March 15, 2000

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8.0 PROJECT MANAGEMENT

Effective management of technical resources, financial budgets, and schedule compliance is the key to a successful project. Project Management's communications with the technical and administrative project team, the regulatory agencies, and the stakeholder is a critical component in the management approach for this task. This section will address the following project management components:

- Project management organization;
- Resources;
- Communication;
- Quality management and nonconformance;
- Site access and control; and
- Work Plan deviations.

8.1 PROJECT MANAGEMENT ORGANIZATION

The organization for project management is shown in Figure 8-1. The team is composed of individuals from AFCEE, the stakeholders, Jacobs, and specialty subcontractors. Responsibilities for key positions are described below.

8.1.1 AFCEE Project Coordinator

The AFCEE Project Coordinator provides oversight of the project, controls funds, and reviews all documents for accuracy and consistency. The AFCEE Project Coordinator is the point of contact for the regulatory agencies and coordinates cleanup activities with base operations. The bog separation project will be under the supervision and management of Ms. Nancy Balkus. All communications will be directed through Ms. Balkus who is the designated representative for MMR on this project.

8.1.2 Jacobs Program Management

Jacobs' program management includes three key positions: Program Manager, Quality Assurance Manager, and Program Health and Safety Manager. These key positions are described in the following paragraphs.

The Jacobs Program Manager is responsible for the successful completion of the project. The Program Manager is responsible for providing adequate resources, monitoring financial and schedule performance, ensuring that required QC activities have been performed, and ultimately approving project deliverables.

The Jacobs Quality Assurance Manager is responsible for developing and updating the MMR QPP (AFCEE 1998a) to conform with AFCEE, Jacobs, and EPA requirements. He also verifies project compliance to all required QA/QC procedures established in the MMR QPP (AFCEE 1998a). The Quality Assurance Manager coordinates field and laboratory audits and programmatic audits on a periodic basis and reviews all work plans and report deliverables before they go to the Program Manager for review and approval.

The Jacobs Program Health and Safety Manager (PHSM), also known as the Health and Safety Officer (HSO), is responsible for the health and safety of all personnel working on the project sites. The PHSM provides initial health and safety training for all site personnel before field activities begin. Also, the PHSM enforces safety standards and procedures during the implementation of fieldwork, holds daily tailgate meetings, and monitors all health and safety-related site conditions.

8.1.3 Jacobs Project Management

The Jacobs Project Manager, Tom Szymoniak, is responsible for coordinating the technical aspects of the project and managing the budget and schedule. Mr. Szymoniak will orchestrate and integrate various technical disciplines to attain the project objective. He is responsible for ensuring the quality of the work product and that all appropriate QC activities have been performed and documented. Mr.

Szymoniak will communicate with the designated AFCEE representative on a regular basis to discuss project progress, potential constraints, and project work. Mr. Szymoniak reports directly to the operations leads.

8.2 COMMUNICATIONS

Communications is a vital part of any remediation project where a potential risk to the public health and environment exists. Communication between AFCEE and the groups described in the following sections will be stressed.

8.2.1 Contractors

Contractors will conduct meetings or develop status reports on a weekly basis to discuss the progress of the project, projected work, locations of work, the conditions of the budget, the project schedule, and project problems and the their corrective actions.

8.2.2 Regulatory Agencies

AFCEE will communicate with the regulatory agencies both in private, during public meetings, and when the summary progress reports are produced. When necessary, the AFCEE Project Manager will contact the appropriate regulatory agency representative(s) to discuss the MMR project and resolve outstanding issues. This project will be one of those covered in the regular weekly technical update meetings.

8.2.3 Local Stakeholders

Continued community involvement is important to the success of the MMR Program. A community outreach program has been initiated in response to public interviews. AFCEE has developed the MMR Community Involvement Plan (CIP) describing the public communication process for the IRP. This plan will allow for public notification of the cleanup progress at MMR (AFCEE 1998a).

8.3 QUALITY MANAGEMENT AND NONCONFORMANCE

The AFCEE/IRP is responsible for ensuring that all IRP activities are conducted in conformance with Air Force policy and quality guidelines. Contractors are subject to the same strict QC requirements. When AFCEE notes noncompliance to required field and QC procedures, the appropriate MMR staff will initiate immediate corrective action. The AFCEE/IRP Manager will be notified of the noncompliance and the planned corrective action.

Jacobs has developed a QPP that describes the programmatic quality guidelines for the MMR program. This plan provides the quality requirements of the overall program.

8.4 SITE ACCESS AND CONTROL

MMR is an active military base and access to sensitive areas is controlled. All subcontracted personnel will contact the AFCEE/IRP Office at least five working days before arrival to allow time for the base to arrange site access.

8.5 WORK PLAN DEVIATIONS

Deviations from the approved Work Plan may occur because of unforeseen conditions in the field. AFCEE, the regulatory agencies, and the Jacobs Task Manager or his designee (Field Manager) must approve all deviations from approved methodologies and procedures. All Work Plan deviations will be documented as Project Notes with a detailed description of the following:

- Procedure not performed;
- Conditions requiring procedure deviation;
- Implemented change to the procedure; and
- Approval signature and date of the procedure modification.

9.0 REFERENCES

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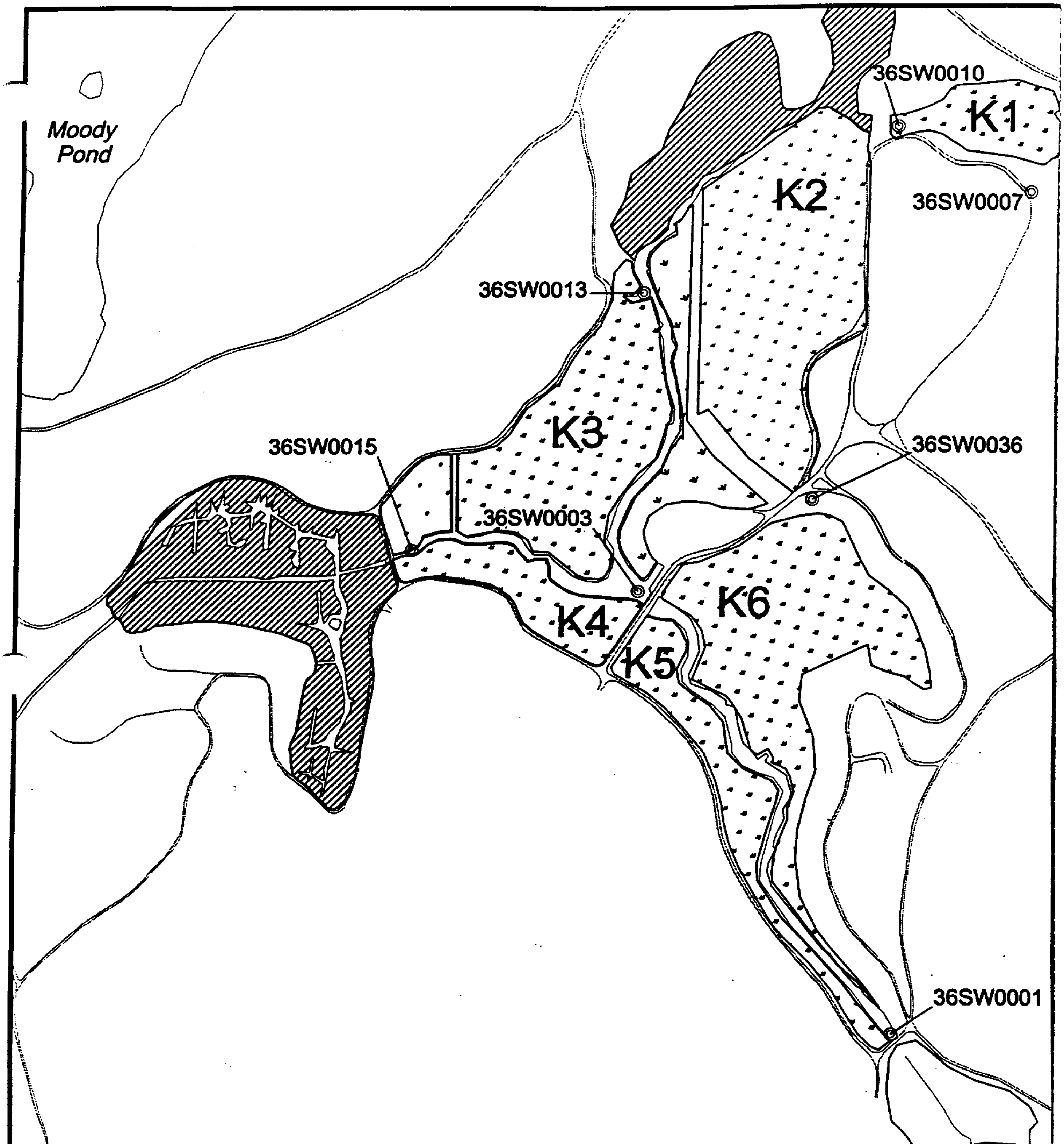

Legend

Bog

Surface Water Sample

Wetland

0 350

Scale in Feet

JACOBS ENGINEERING

Quashnet River
Cranberry Bog

Massachusetts Military Reservation
Cape Cod, Massachusetts

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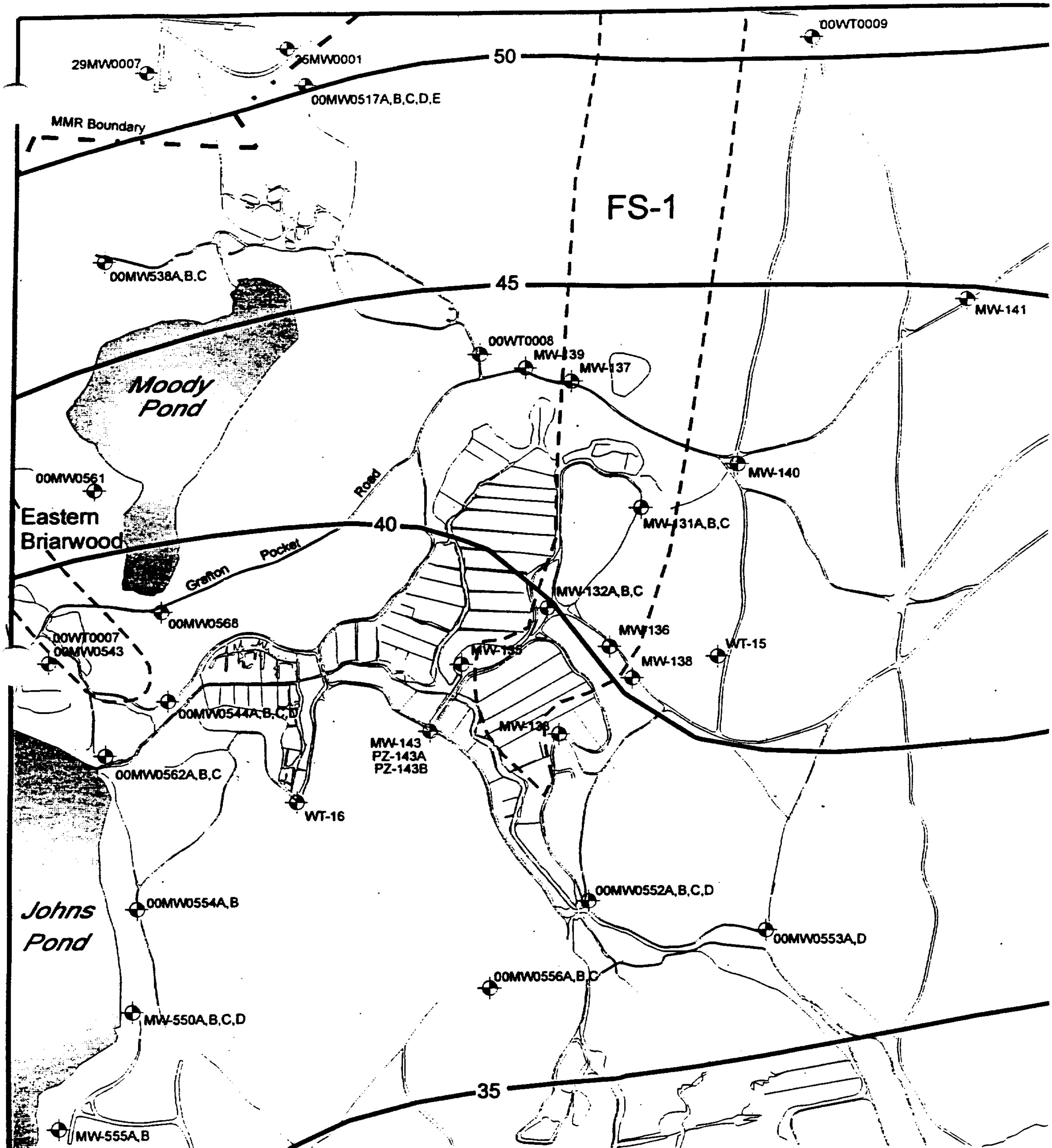
Figure 1-3



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Monitoring Well

Plume Outline

—40 — Groundwater Contours / 5ft Intervals

0 700

Scale in Feet

JE JACOBS ENGINEERING

Plan View of
Monitoring Wells at
FS-1

Massachusetts Military Reservation
Cape Cod, Massachusetts

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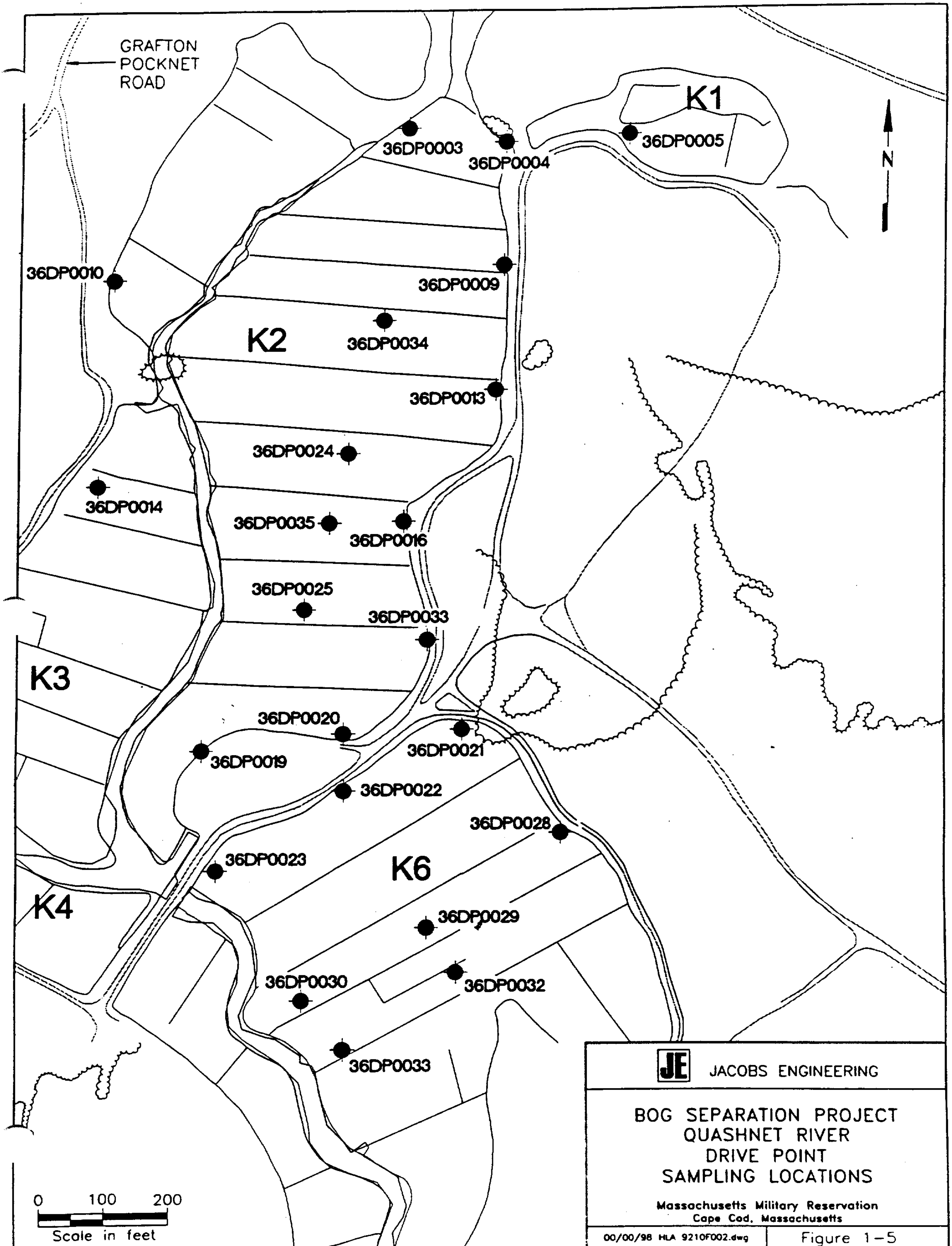
Figure 1-4



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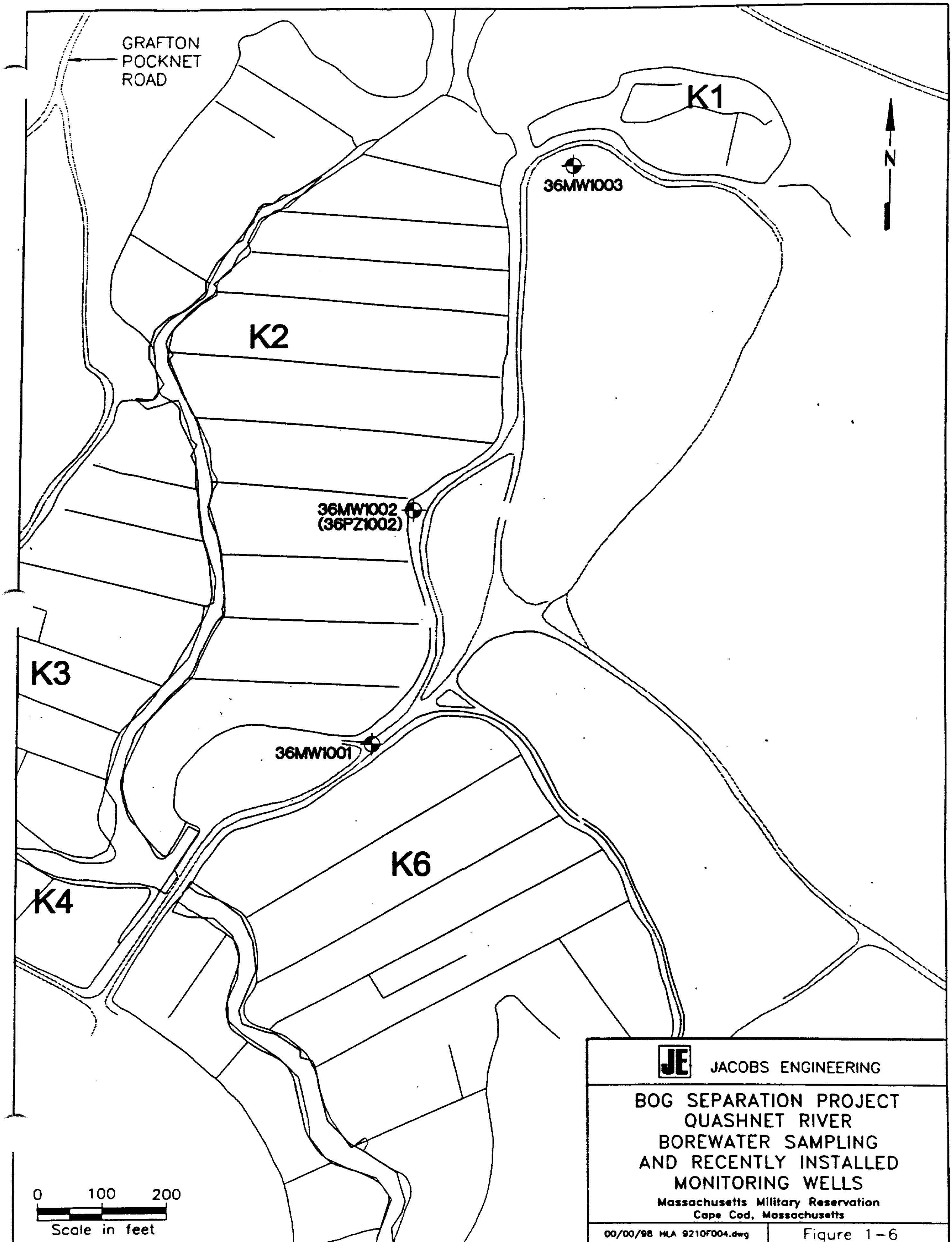

JACOBS ENGINEERING

BOG SEPARATION PROJECT
QUASHNET RIVER
BOREWATER SAMPLING
AND RECENTLY INSTALLED
MONITORING WELLS

Massachusetts Military Reservation
Cape Cod, Massachusetts

00/00/98 HLA 9210F004.dwg | Figure 1-6

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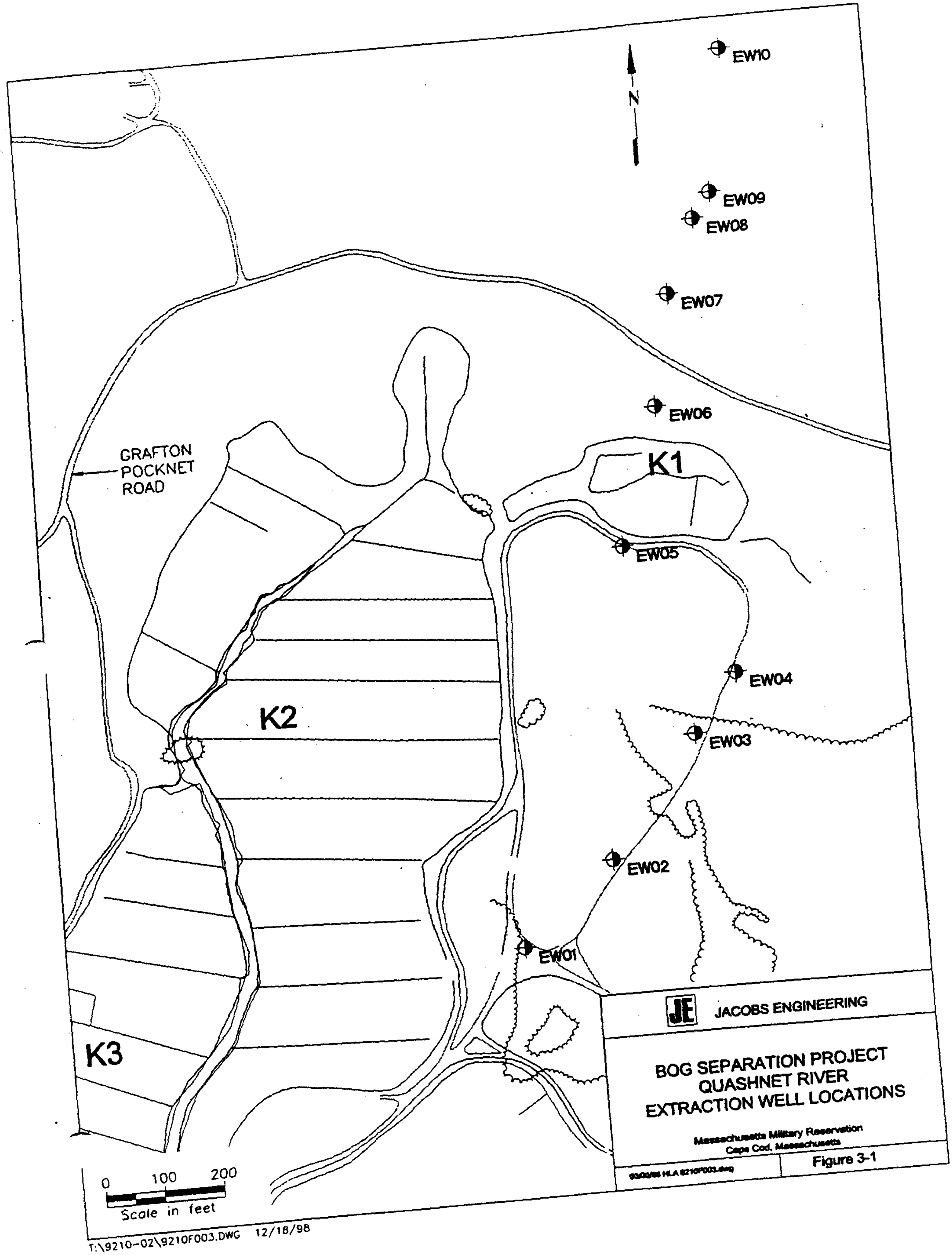

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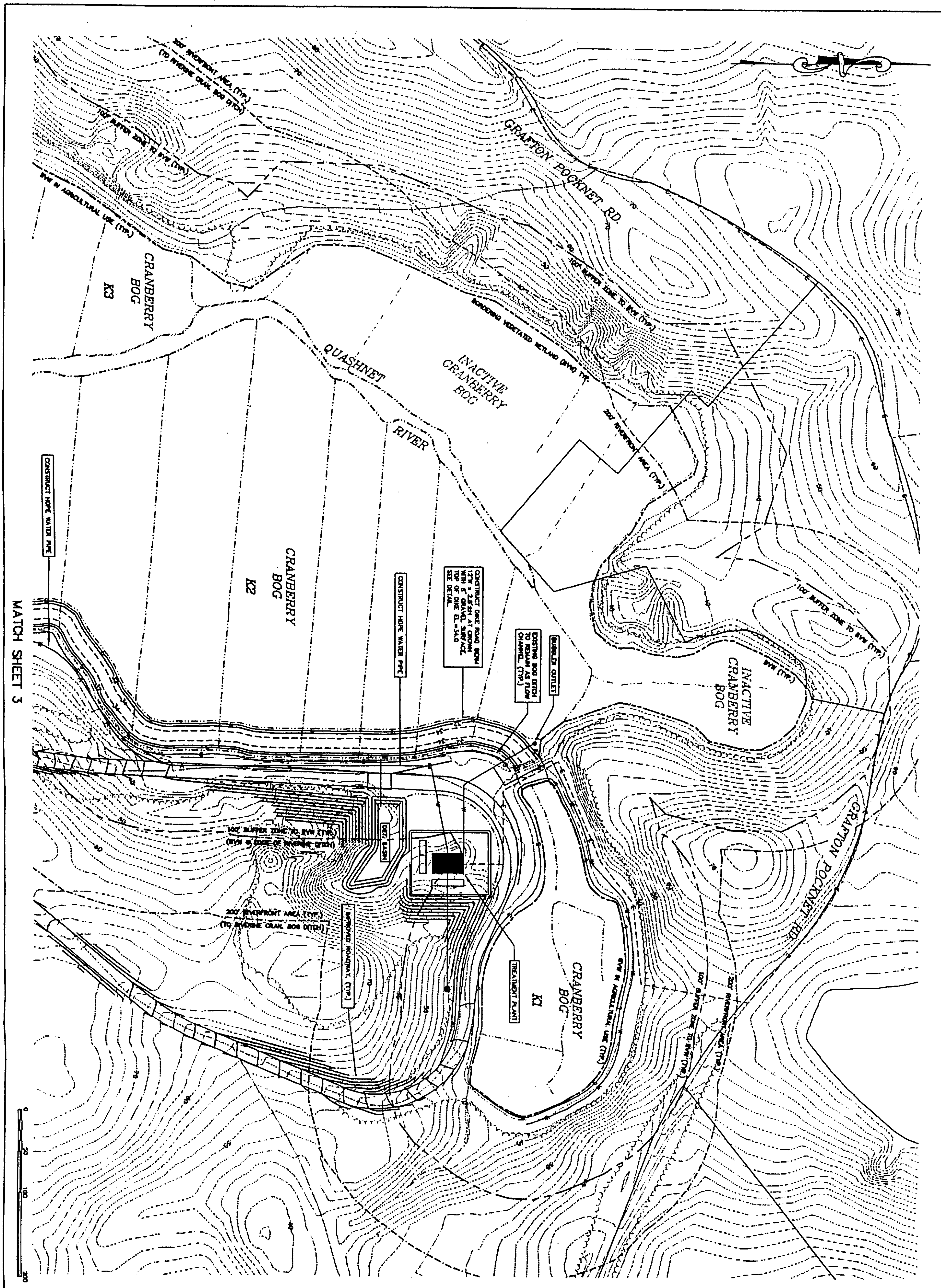
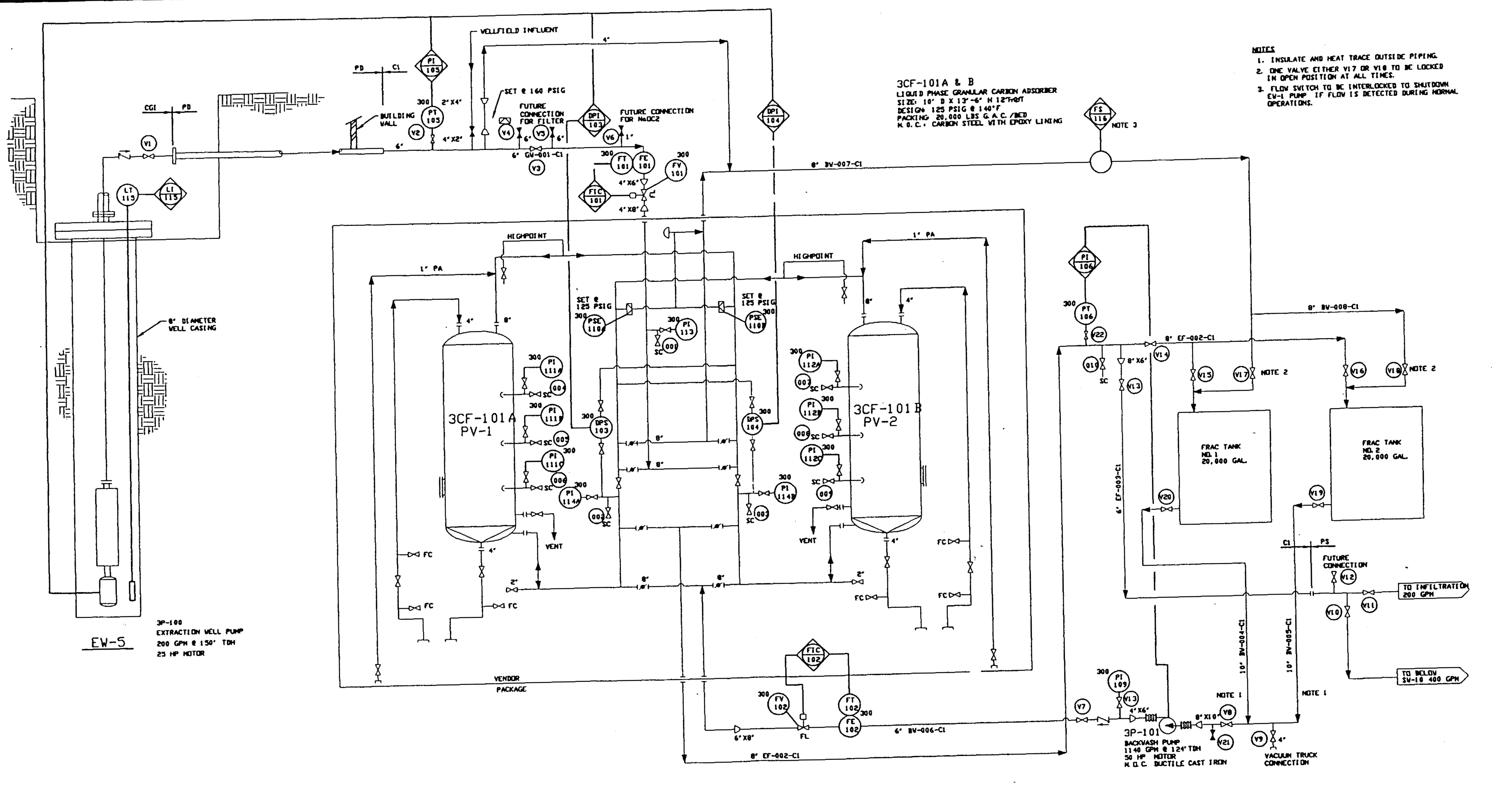


DWG. Figure 3-7	JOB NO.: 98-4355	PLAN OF CRANBERRY BOG/ RIVER SEPARATION PREPARED FOR: MMR/JACOBS ENGINEERING GROUP, INC. QUASHNET RIVER MASHPEE, MA.	G.A.F. ENGINEERING, INC. PROFESSIONAL ENGINEERS & LAND SURVEYORS 454 WAREHAM STREET, PO BOX 853, MARION, MA 02738 TEL: (508) 748-0252 FAX: (508) 748-0642 E-MAIL: gafeng@capecod.net	APPROVED BY:	APPROVED BY:

DATE: 12-16-98
DRAWN BY: P.A.W.
CHECKED BY: W.F.M.
JOB NO.: 98-4355
SCALE: 1" = 50'

REV.	DATE	BY	APP'D	DESCRIPTION



Legend

JACOBS ENGINEERING

Process Instrument Diagram
for
Treatment System

Massachusetts Military Reservation
Cape Cod, Massachusetts

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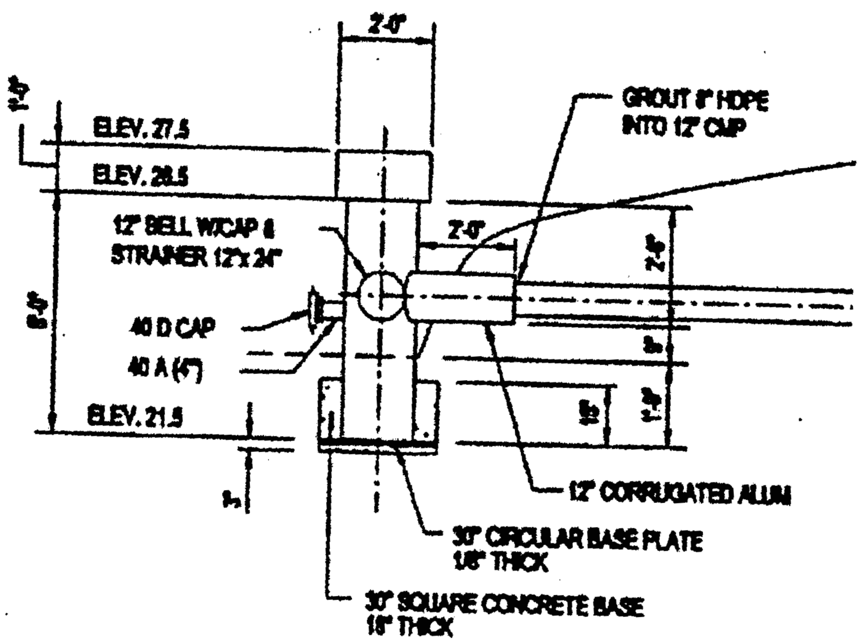

JACOBS ENGINEERING

Bubbler Detail

Massachusetts Military Reservation
Cape Cod, Massachusetts

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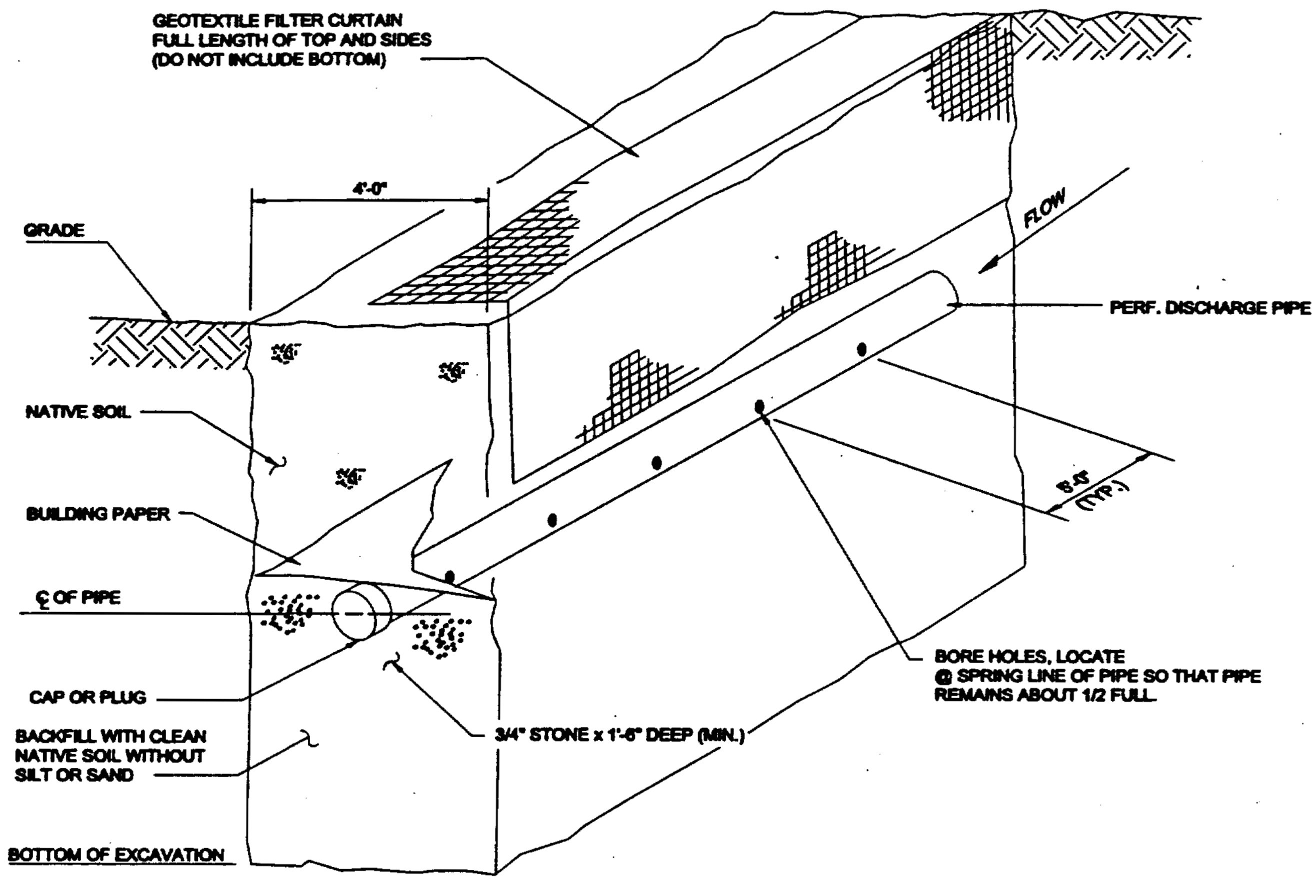
Figure 3-9



SUBSURFACE INFILTRATION FIELD

N.T.S.

JE JACOBS ENGINEERING

BOG SEPARATION PROJECT
QUASHNET RIVER
SUBSURFACE INFILTRATION FIELD

Massachusetts Military Reservation
Cape Cod, Massachusetts

12/18/98 HLA 9210F001.dwg | Figure 3-10

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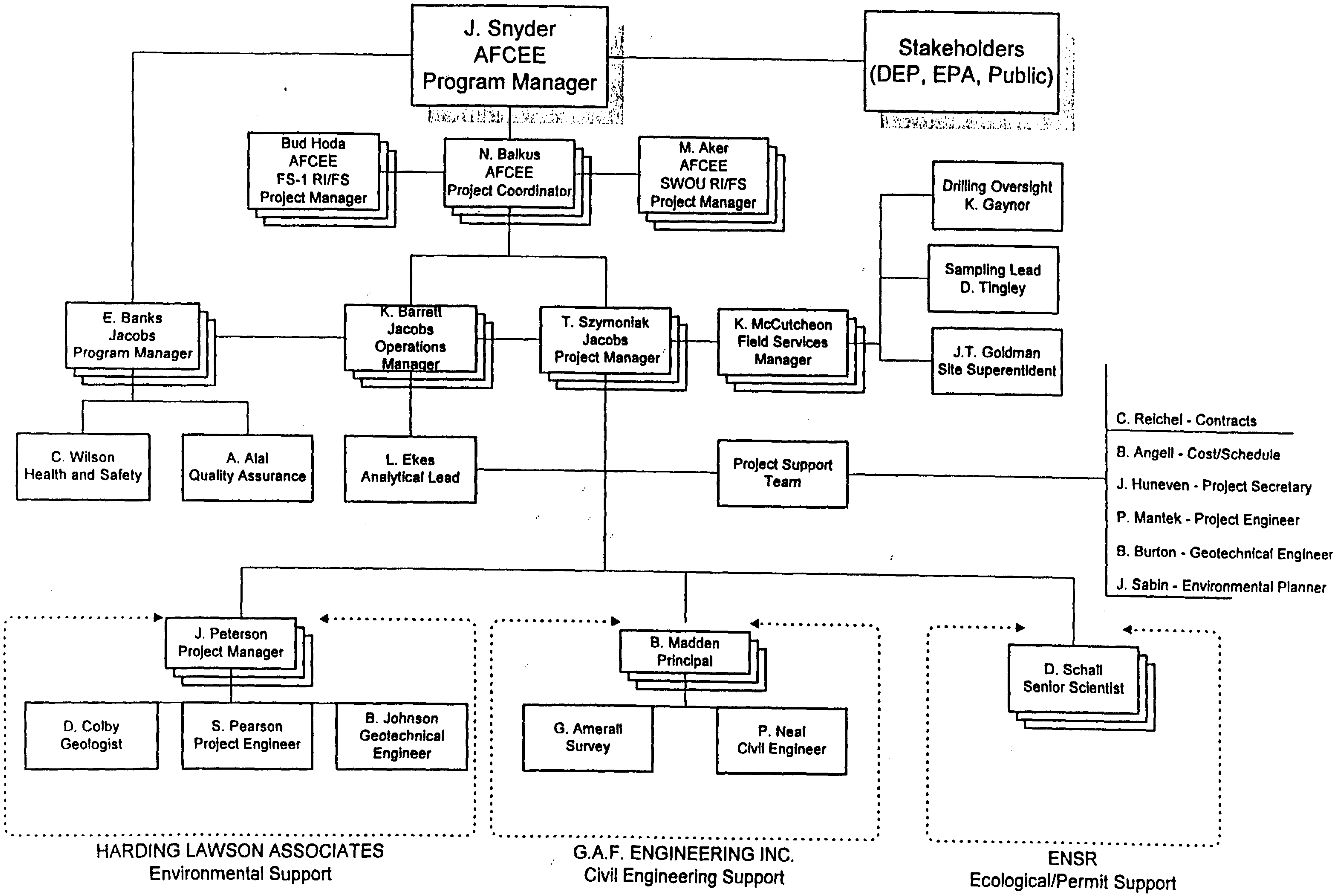
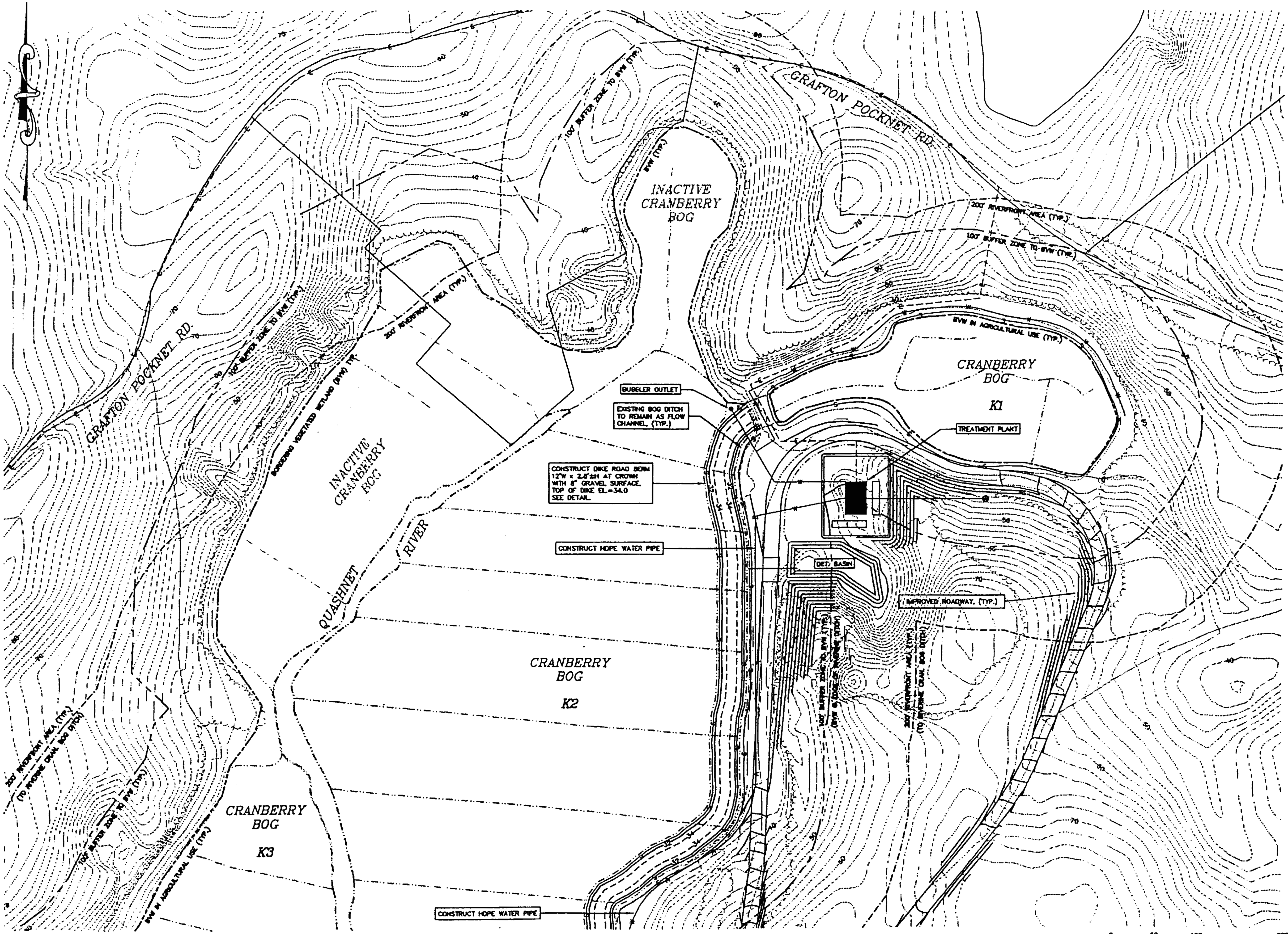
Organizatior)art
Bog Separation Project





MATCH SHEET 3

REV.	DATE	BY	APP'D	DESCRIPTION

DATE: 12-16-98
DRAWN BY: P.A.W.
CHECKED BY: W.F.M.
JOB NO.: 98-4355
SCALE: 1" = 50'

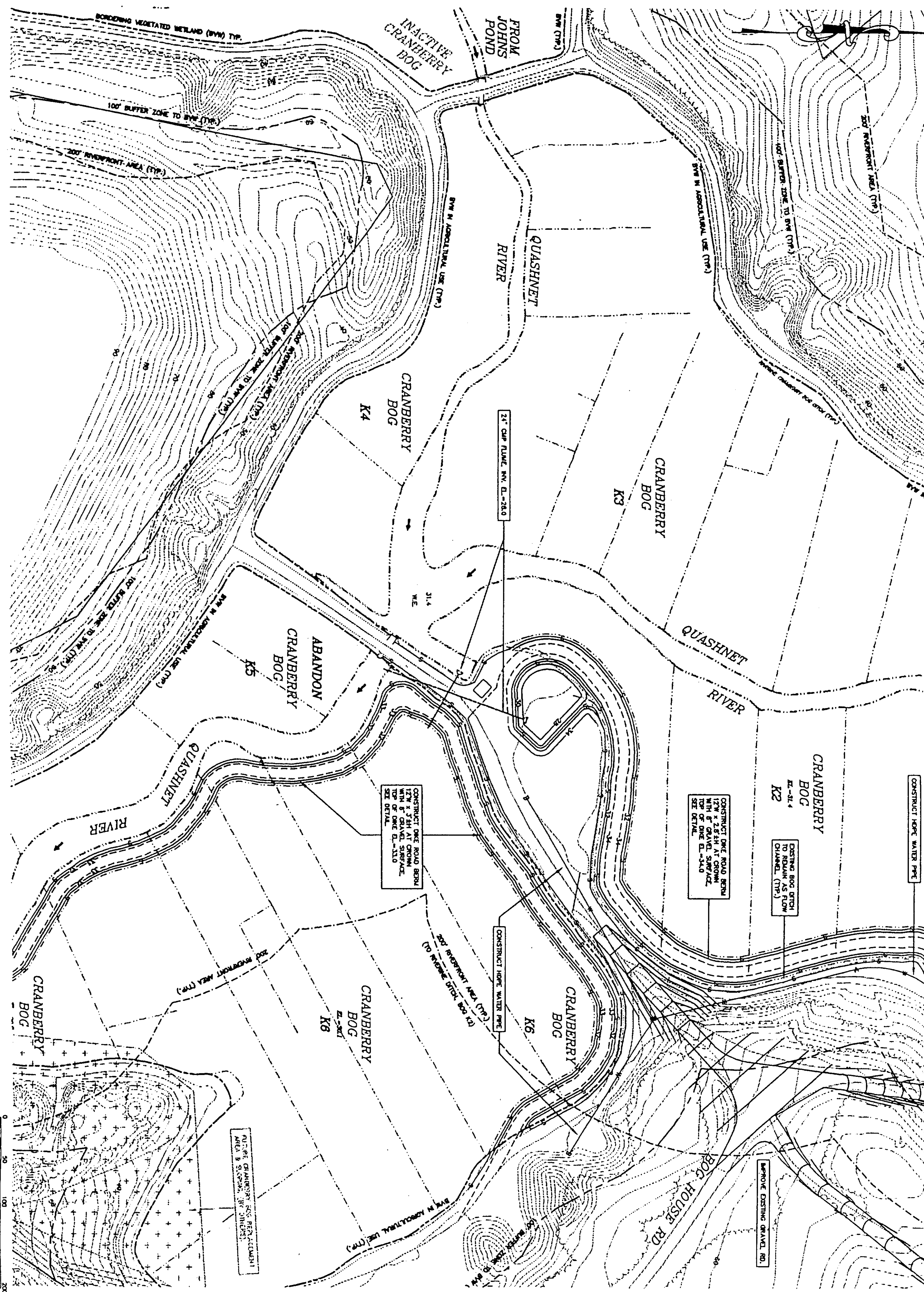
APPROVED BY:

APPROVED BY:

G.A.F. ENGINEERING, INC.
PROFESSIONAL ENGINEERS & LAND SURVEYORS
454 WAREHAM STREET, PO BOX 853, MARION, MA 02738
TEL: (508) 748-0252 FAX: (508) 748-0642
E-MAIL: gafeng@capecod.net

PLAN OF CRANBERRY BOG/ RIVER SEPARATION
PREPARED FOR:
MMR/JACOBS ENGINEERING GROUP, INC.
QUASHNET RIVER MASHPEE, MA

JOB NO.: 98-4355
DWG. 2 OF 5

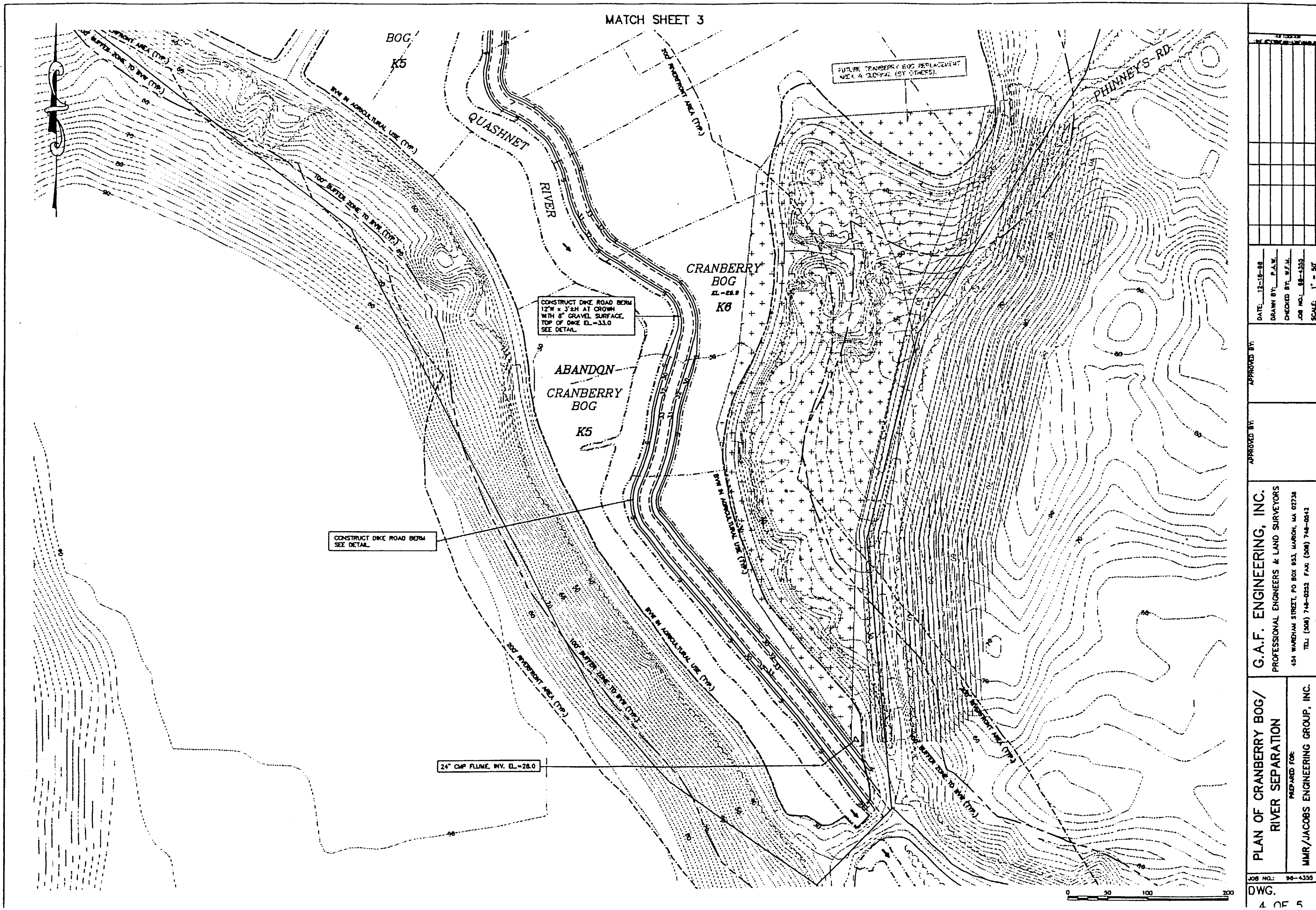


DWG. 3 OF 5	JOB NO.: 98-4355	PLAN OF CRANBERRY BOG/ RIVER SEPARATION PREPARED FOR: MMR/JACOBS ENGINEERING GROUP, INC. QUASHNET RIVER MASHPEE, MA	G.A.F. ENGINEERING, INC. PROFESSIONAL ENGINEERS & LAND SURVEYORS 454 WAREHAM STREET, PO BOX 953, MARION, MA 02738 TEL: (508) 748-0252 FAX: (508) 748-0542 E-MAIL: gafeng@capecod.net

APPROVED BY:

APPROVED BY:

DATE: 12-18-98
DRAWN BY: P.A.W.
CHECKED BY: W.F.M.
JOB NO.: 98-4355
SCALE: 1" = 50'


MATCH SHEET 3
BOG
K5
QUASHNET
RIVER
PHINNEY'S RD.
FUTURE CRANBERRY BOG REPLACEMENT AREA & CLORING (BY OTHERS)
200' RIVERFRONT AREA (TYP.)
100' BUFFER ZONE TO BVW (TYP.)
BVW IN AGRICULTURAL USE (TYP.)
CRANBERRY BOG
EL.=28.9
K6
ABANDON CRANBERRY BOG
K5
CONSTRUCT DIKE ROAD BERM 12'W x 3'±H AT CROWN WITH 6" GRAVEL SURFACE, TOP OF DIKE EL.=33.0 SEE DETAIL
CONSTRUCT DIKE ROAD BERM SEE DETAIL
24" CMP FLUME, INV. EL.=28.0
0 50 100 200
PLAN OF CRANBERRY BOG/ RIVER SEPARATION
PREPARED FOR:
MMR/JACOBS ENGINEERING GROUP, INC.
QUASHNET RIVER
MASHPEE, MA.
G.A.F. ENGINEERING, INC.
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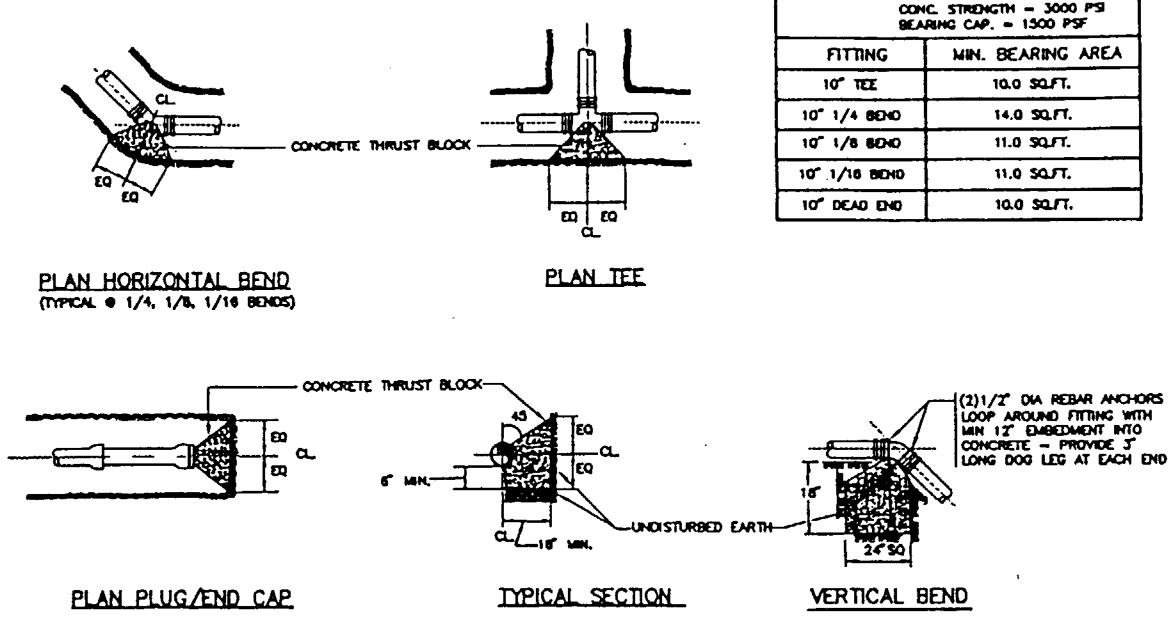
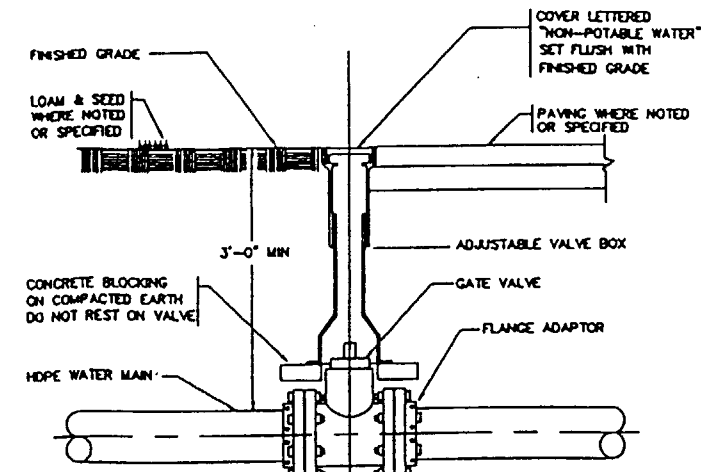
TEL: (508) 748-0232 FAX: (508) 748-0542
E-MAIL: gafeng@capecod.net
APPROVED BY:
APPROVED BY:
DATE: 12-18-98
DRAWN BY: P.A.W.
CHECKED BY: W.F.M.
JOB NO.: 98-4335
SCALE: 1" = 50'
REV.
DATE
BY
APP'D
DESCRIPTION
JOB NO.: 98-4335
DWG.
4 OF 5

CONCRETE ANCHOR REQUIREMENTS	
BASED ON:	TEST PRESSURE = 150 PSI CONC. STRENGTH = 3000 PSI BEARING CAP. = 1500 PSF
FITTING	MIN. BEARING AREA
10" TEE	10.0 SQ.FT.
10" 1/4 BEND	14.0 SQ.FT.
10" 1/8 BEND	11.0 SQ.FT.
10" 1/16 BEND	11.0 SQ.FT.
10" DEAD END	10.0 SQ.FT.



CONCRETE THRUST BLOCK DETAILS
NO SCALE



DETAIL (IN ROADWAY) GATE VALVE INSTALLATION
NO SCALE

NOTES:
1. SIDE SLOPES SHALL NOT EXCEED 3:1 EXCEPT FOR THE INTERIOR DIKES. EXPOSED SIDE SLOPES SHALL BE DRESSED WITH 4 TO 6 INCHES OF TOPSOIL.

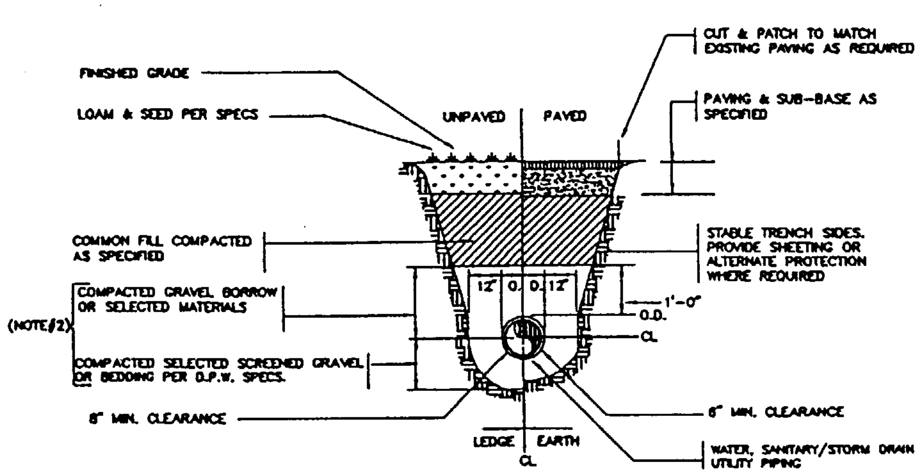
2. PERMANENT SEEDING (BEFORE SEPTEMBER 15) LIME TO PH OF 6.5 ACCORDING TO SOIL TEST OR APPLY AT THE RATE OF 100 TO 150 LBS. PER 1,000 SQUARE FEET. APPLY 10-20-20 FERTILIZER AT 1,000 LBS. PER ACRE. INCOPORATE LIME AND FERTILIZER IN TOP 4 INCHES OF SOIL. SEED 100 LBS. PER ACRE OF THE FOLLOWING SEED MIX.

PURE PERCENT	SEED
30-35%	CREEPING RED FESCUE
30-35%	PERENNIAL RYEGRASS
20-25%	KENTUCKY BLUEGRASS
10-15%	ANNUAL RYEGRASS

HYDRO SEEDING IS AN ALTERNATIVE FOR THIS APPLICATION. A MIXTURE OF SEED WATER AND MULCH IS SPRAYED ON THE SEED BED COMBINING THREE (3) SEPRATE ACTIONS INTO ONE (1) OPERATION

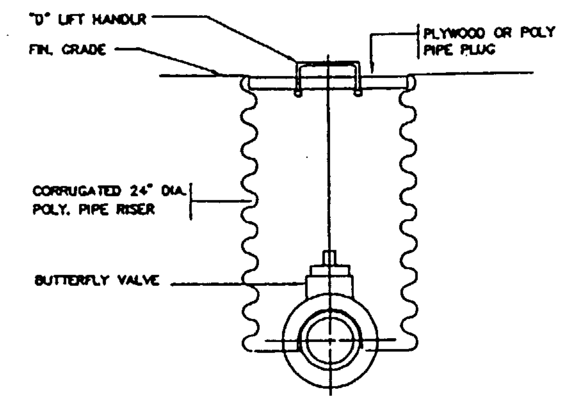
3. ALL ELEVATIONS ARE BASED ON N.G.V. DATUM.

4. ALL CONSTRUCTION SHALL CONFORM WITH N.C.R.S. BEST MANAGEMENT PRACTICES.

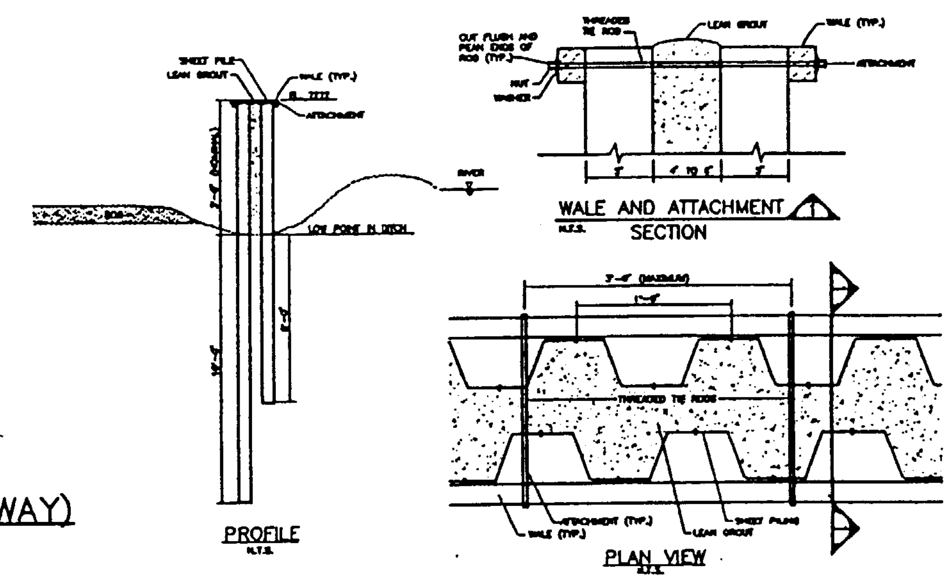


TYPICALTRENCH DETAIL
NOT TO SCALE

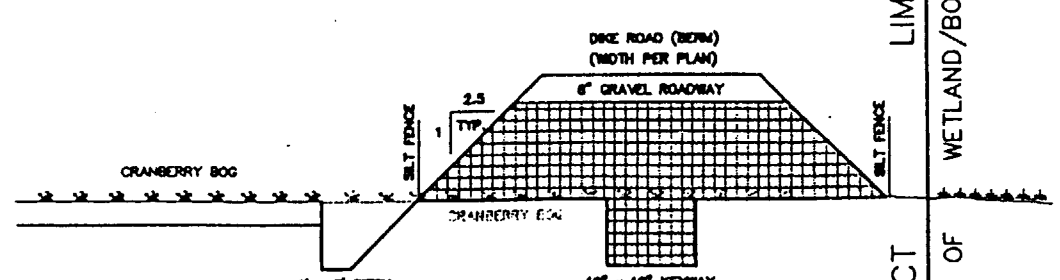
NOTES: 1. MINIMUM DEPTH OF BURY FOR WATER PIPING SHALL BE 3'-0"
2. BACK FILL AROUND P.V.C. PIPE SHALL BE WASHED SAND. NO MATERIAL EXCAVATED FROM TRENCH SHALL BE PERMITTED. COMPACT IN 6" LIFTS.



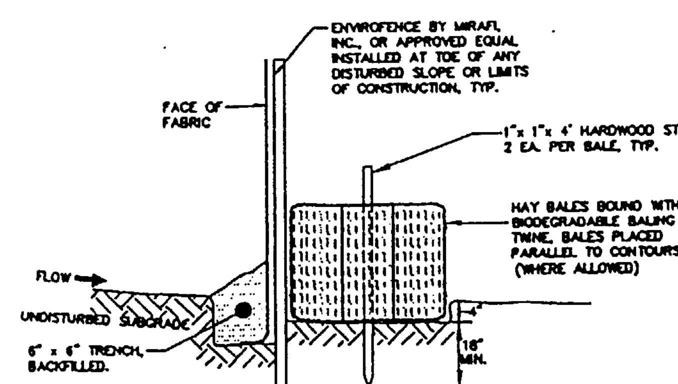
ALTERNATE VALVE BOX RISER (OFF ROADWAY)
NO SCALE



SHEET PILE WALL DETAIL
N.T.S.



DIKE ROAD DETAIL
N.T.S.



NOTES:
1. SILTATION FENCE SHALL BE "ENVIROFENCE" AS MANUFACTURED BY MIRAFI, INC. OR AN APPROVED EQUAL.
2. SILTATION FENCING SHALL BE INSTALLED DOWNSLOPE OF ALL PROPOSED AND EXISTING DISTURBED AREAS, OR AS SHOWN ON THE PLANS.
3. EROSION CONTROL MEASURES SHALL BE MAINTAINED UNTIL VEGETATIVE COVER HAS BEEN FIRMLY ESTABLISHED.
4. EROSION CONTROL MEASURES SHALL FOLLOW THE PERFORMANCE STANDARDS OF THE USDA SOIL CONSERVATION SERVICE, AND ANY APPLICABLE STATE/LOCAL CONSERVATION AUTHORITY.

SILTATION BARRIER DETAIL
N.T.S.

AS-NOTED

DATE: 10-22-98
DRAWN BY: P.A.W.
CHECKED BY: W.F.M.
JOB NO.: 98-4355
SCALE: AS-NOTED

APPROVED BY:

APPROVED BY:

G.A.F. ENGINEERING, INC.
PROFESSIONAL ENGINEERS & LAND SURVEYORS
454 WAREHAM STREET, PO BOX 953, MARION, MA 02738
TEL: (508) 748-0252 FAX: (508) 748-0642

CONSTRUCTION DETAILS

PREPARED FOR:
MMR/JACOBS ENGINEERING GROUP, INC.

JOB NO.: 98-4355

DWG.
5 OF 5

APPENDIX F

Town of Mashpee Groundwater Moratorium

Town of Mashpee

MORATORIUM ON GROUND WATER WELLS

Under the authority of Massachusetts General Laws, Chapter 111, Section 31, the Board of Health of Mashpee adopts the following regulation in an effort to better protect the public health and welfare of the citizens and visitors in the Town:

REGULATION:

Residential wells located in documented or anticipated areas of groundwater contamination as defined by the Board of Health are herewith restricted from use for any purpose, including drinking, any agricultural use (lawn watering, gardening, livestock watering, irrigation of crop land, etc.), washing vehicles, pool filling, etc. This moratorium includes groundwater wells owned by residents currently connected to a public water supply.

The affected wells must be decommissioned by a Massachusetts Licensed Well Driller and written evidence thereof must be submitted to the Board of Health.

PURPOSE:

This regulation seeks to prevent any inadvertent exposure to contaminated groundwater which may present a potential health risk to the residents and visitors of Mashpee. Residential well waters in documented or potentially affected areas of groundwater pollution pose a possibility of exposure pathways to humans. Ingestion, inhalation and dermal exposure are potential pathways. This potential risk necessitates this regulation.

Adopted by the Board of Health on April 23, 1998. This regulation will become effective upon the date of publication in the press.

THE BOARD OF HEALTH

Lockheed Martin Energy Systems
Hazardous Waste Remedial Actions Program
Post Office Box   Oak Ridge, Tennessee 37831 - 7606
Telephone: 423-241-9758   Facsimile: 423-241-9400

LOCKHEED MARTIN

May 27, 1999

Mr. Jim F. Snyder
Restoration Program Manager
HQ AFCEE/MMR
322 East Inner Road, Box 41
Otis Air National Guard Base, Massachusetts 02542-5028

Dear Mr. Snyder:

Final FS-1 Feasibility Study

As directed by the Air Force Center for Environmental Excellence, the Hazardous Waste Remedial Actions Program is hereby providing 22 bound copies and 1 unbound copy of the "Final Feasibility Study Area of Contamination FS-1," dated May 1999. The electronic copy will be provided in a separate transmittal. Copies are also being sent to the regulatory agencies.

If you have any questions or comments, please contact me at 423-241-9174.

Sincerely,

J. W. Johnston

J. W. Johnston, Jr., Project Manager
Hazardous Waste Remedial Actions Program

JWJ:rlh

Enclosures

cc: P. Marchessault, EPA (5 copies)
L. Pinaud, MADEP (5 copies)
File-RC

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
INSTALLATION RESTORATION PROGRAM
OTIS AIR NATIONAL GUARD BASE, MA 02542-5028

4 Jun 1999

MEMORANDUM FOR SAF/LLP
ATTENTION: MS CHARLOTTE MOYER

FROM: HQ AFCEE/MMR
322 East Inner Road, Box 41
Otis ANG Base, MA 02542-5028

SUBJECT: Final Report

1. Please be advised that the following have been issued as final documents:

(1) "Final Proposed Plan for Cleanup to FS-1" dated June 1999
(2) "Final Feasibility Study AOC FS-1" dated May 1999

2. If you have any questions, please call Bud Hoda (508) 968-4670, extension 4918.

JIM F. SNYDER
Remediation Program Manager

cc
Bud Hoda (w/o atch)

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
INSTALLATION RESTORATION PROGRAM
OTIS AIR NATIONAL GUARD BASE, MA 02542-5028

4 Jun 1999

MEMORANDUM FOR AFCEE/ERC
ATTENTION: MS. BARBARA SMITH-TOWNSEND

FROM: HQ AFCEE/MMR
322 East Inner Road, Box 41
Otis ANG Base, MA 02542-5028

SUBJECT: Final Documents

1. Attached please find three copies each of the following documents:

(1) "Final Proposed Plan for Cleanup Related to FS-1" dated June 1999
(2) "Final Feasibility Study AOC FS-1" dated May 1999

2. If you have any questions, please call Bud Hoda (508) 968-4670, extension 4918.

JIM F. SNYDER
Remediation Program Manager

Attachments:
Documents (3 copies each)

cc:
Bud Hoda (w/o atch)

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
INSTALLATION RESTORATION PROGRAM
OTIS AIR NATIONAL GUARD BASE, MA 02542-5028

4 Jun 1999

MEMORANDUM FOR AFCEE/JA
ATTENTION: MR. WILLIAM DICK

FROM: HQ AFCEE/MMR
322 East Inner Road, Box 41
Otis ANG Base, MA 02542-5028

SUBJECT: Final Documents

1. Attached please find one copy each of the following documents:

(1) "Final Proposed Plan for Cleanup Related to FS-1" dated June 1999
(2) "Final Feasibility Study AOC FS-1" dated May 1999

2. If you have any questions, please call Bud Hoda (508) 968-4670, extension 4918.

JIM F. SNYDER
Remediation Program Manager

Attachments:
Document (one copy each)

cc:
Bud Hoda (w/o atch)

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
INSTALLATION RESTORATION PROGRAM
OTIS AIR NATIONAL GUARD BASE, MA 02542-5028

4 Jun 1999

MEMORANDUM FOR NGB-PAI-E
ATTENTION: MR. JOHN REINDERS

FROM: HQ AFCEE/MMR
322 East Inner Road, Box 41
Otis ANG Base, MA 02542-5028

SUBJECT: Final Documents

1. Attached please find one copy each of the following documents:

(1) "Final Proposed Plan for the Cleanup to FS-1" dated June 1999
(2) "Final Feasibility Study AOC FS-1 " dated May 1999

2. If you have any questions, please call Bud Hoda (508) 968-4670, extension 4918.

JIM F. SNYDER
Remediation Program Manager

Attachments:
Documents (one copy each)

cc:
Bud Hoda (w/o atch)